SPLIT SYSTEMS

A PRIMER

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INTRODUCTION

A *split system* is an air-conditioning or heat pump system that uses refrigerant as the heat exchange fluid and has an evaporator, compressor, and condenser as separate components. In most modern commercial applications, the compressor and condenser are combined into a single piece of equipment called a condensing unit. Refrigerant piping, custom-designed to meet the physical requirements of each individual application, connects the system components.

A typical residential central air-conditioning system is a split system. The compressor and condenser are combined as a single condensing unit mounted outdoors. The evaporator, a finned coil, is mounted in a section of ductwork downstream of the furnace blower. Two flexible refrigerant lines, one for gas and one for liquid, connect the components.

This white paper is intended as a primer on light commercial and industrial split systems. It reviews basic design and installation requirements, equipment, application rules of thumb, key specification differentiators, and typical applications for split systems.

SPLIT SYSTEM BASICS

A typical split air-conditioning system is shown in Figure 1. The key features that designate this as a split system are:

- Refrigerant is the working fluid
- Physical separation of the evaporator and condenser (condensing unit)

Heat pumps are also split systems and are distinguished by their ability to reverse the evaporator and condenser functions within the system.

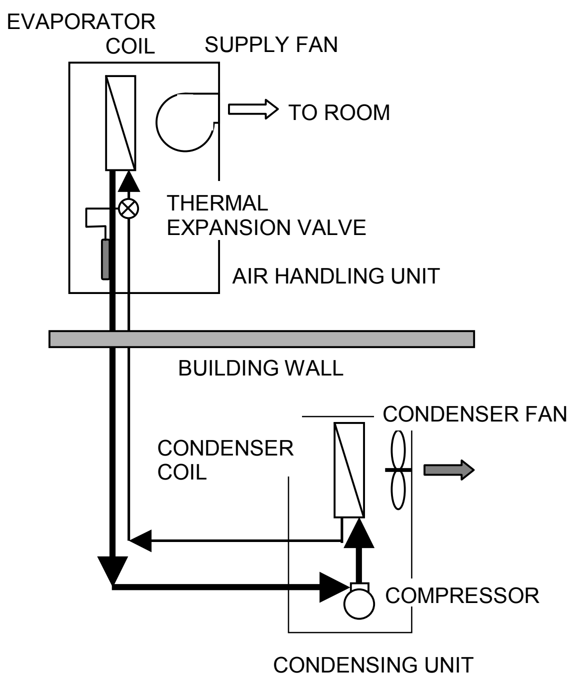

Figure 1. Typical Split System Schematic

Evaporator

For discussion purposes, the evaporator is the starting point of the refrigerant cycle. High-pressure liquid refrigerant is throttled to the evaporator through a thermostatic expansion valve. Because the liquid is throttled, the pressure in the evaporator is less than the saturation pressure of the entering liquid refrigerant. This causes the liquid refrigerant to boil. The heat needed to boil refrigerant is drawn from the medium surrounding the evaporator, usually air or water.

The evaporator can be considered the point of heat capture in an air-conditioning system. Heat from the water or air stream used to cool the building is transferred to the refrigerant gas, leaving the evaporator.

Evaporators fall into two categories: *dry* type and *flooded* type. Flooded evaporators are designed to have a constant level of liquid refrigerant in the evaporator. Dry evaporators, usually called direct-expansion evaporators, are designed to process only the amount of refrigerant needed to meet the current load.

In most comfort cooling systems, the evaporator is a direct-expansion, finned, tubular coil that has refrigerant inside the tubes. A fan draws air across the finned exterior of the tubes and delivers it to the spaces being conditioned. Standard coil construction consists of copper tubes with aluminum fins mounted in a galvanized steel frame.

Chilled water systems can use either a flooded evaporator or a direct-expansion evaporator; both are typically a shell-and-tube heat exchanger. In a flooded evaporator, refrigerant floods the shell side of the heat exchanger and is controlled by a level valve. Water being chilled passes through the tubes. Conversely, in a direct-expansion evaporator, water is carried in the shell and refrigerant is boiled inside the tubes. The rate of refrigerant flow is throttled to insure that only refrigerant gas exits the evaporator. Copper tubes mounted within a carbon steel shell is the most common construction used for chilled water evaporators.

The capacity of a direct-expansion coil is a function of the air volume passing through the coil, and the entering dry- and wet-bulb air temperatures. If there is an increase in the airflow rate through a coil or the temperature difference between the air and the refrigerant is increased, the coil's heat transfer capacity increases. Likewise, a decrease in airflow or temperature difference will decrease the coil's capacity.

Compressor

The function of an air-conditioning system is to transfer heat from a relatively low-temperature heat source (indoors) to a relatively high-temperature heat sink (outdoors). Because heat transfer in an air-conditioning system is not driven by the temperature difference between the heat source and the heat sink, energy must be expended through a mechanical refrigeration system to force the heat transfer. The compressor is the point of energy input to the system.

The compressor draws refrigerant gas from the evaporator, compresses it, and then discharges it to the condenser. At this point in the cycle, the refrigerant gas is carrying heat taken from the building.

Compressors in split systems are almost exclusively driven by electric motors. Small split systems of up to about 10 tons usually have fully hermetic reciprocating or scroll type compressors. Large systems of 7.5 tons and larger usually have semi-hermetic reciprocating type compressors. Semi-hermetic compressors offer the benefit of being able to unload pairs of cylinders within a single compressor to provide capacity stages. For instance, a compressor with six cylinders can be staged to operate at 100%, 67% and 33% capacity by operating on six, four, or two cylinders respectively.

Fully hermetic compressors are usually operated as either on or off. Capacity staging in fully hermetic units is accomplished by cycling multiple compressors on or off. A unit with two equally sized fully hermetic compressors may operate at 100% and 50% capacity by starting or stopping one of the two compressors. Some manufacturers will install unequally sized compressors in a unit to achieve a greater staging flexibility without adding more compressors. For instance, a 30-ton unit with two compressors rated at 10 tons and 20 tons will have capacity stages at 33%, 67% and 100%.

Condenser

Hot compressed refrigerant gas leaves the compressor and is condensed to liquid in the condenser. The condenser is the final point of heat exchange, where heat is transferred from the refrigerant to the atmosphere (in air-cooled systems). The condenser capacity must be sufficient to reject heat taken from the building in the evaporator and heat added by the compressor.

In most commercial and industrial split systems, the condenser is air-cooled. Although condensers can be either air-cooled or water-cooled, air-cooling is more common for the primary reasons that air is readily available, it does not need to be chemically or otherwise treated, and it does not require special disposal considerations. Air-cooled systems also generally require less maintenance, have fewer components, and cost less than water-cooled systems. A disadvantage of air-cooled systems is that their capacity for heat rejection decreases at higher outdoor air temperatures. Because peak cooling loads occur when the atmosphere is at its warmest, the condenser must be able to achieve its rated capacity when the air passing through it is upwards of 115°F. This causes the energy consumption of the compressor to be relatively high and requires large volumes of air movement through the condenser coil. Secondary problems associated with air-cooled systems are:

- Condenser capacity increases with decreasing outdoor air temperature and can cause part-load control problems.
- At very low outdoor temperatures, difficulty may be experienced during startup without control compensation to bypass the low-pressure safety switch.

Variable fan-speed control is used to vary airflow through the condenser coils and improve operation at lower ambient temperatures. Cycling fans for condenser control is not recommended.

Typical air-cooled condenser coil construction uses copper tubes with aluminum fins. For coastal regions, industrial areas, or locations with corrosive atmospheres, manufacturers offer different coil construction materials (i.e., all copper) or corrosion resistant coatings.

Refrigerant Piping

The fundamentals of refrigerant piping design are not unlike the fundamentals for any piping system. Care must be exercised in designing refrigerant piping to insure proper operation of the mechanical components. In addition, there are several unique and important considerations:

- The fluid changes state. In some portions of the system it is a liquid and in others a gas.
- The system must be designed for the minimum practical pressure loss. Excessive pressure loss decreases system cooling capacity and causes unnecessary energy consumption.
- A second fluid, lubricating oil, is present in the system and is mixed with the refrigerant. The piping must be designed to promote oil migration back to the compressor.
- Accumulation of liquid refrigerant in the compressor crankcase must be minimized.
- Piping and design features should protect the compressor during operation and shutdown.

Oil Movement. Lubricating oil migrates into the refrigerant piping system from the compressor. With each reciprocating or rotating stroke of the compressor, a small amount of oil that lubricates the pistons or scroll is swept into the discharge stream. High-velocity refrigerant gas leaving the compressor moves the entrained oil to the condenser. In the condenser, oil readily mixes with liquid refrigerant and is carried to the evaporator. In a properly designed system, refrigerant gas leaving the evaporator travels through the pipe at a velocity sufficient to entrain oil droplets and carry them back to the compressor. The rate of refrigerant and oil return must match the rate leaving the compressor.

Friction Loss and Pipe Sizing. The optimum pipe size balances economics, friction loss and oil return. First-cost economics argues for small pipe sizes, but at the expense of operating cost and performance degradation. Friction loss objectives argue for larger pipe sizes, but at the cost of economics and oil return.

Hot Gas Line Sizing. In split systems using a condensing unit, the hot gas line is factory-installed as part of the condensing unit and is not designed by the consulting engineer. For systems with separate compressors and condensers, the consulting engineer must design hot gas piping for field installation.

Excessive pressure loss in the hot gas piping between the compressor and condenser can increase compressor energy consumption and decrease compressor capacity. The usual rule-of-thumb is to limit the hot gas pressure loss to the equivalent of one to two degrees change in saturation temperature. For R-22, this is equal to about 2.9 to 6.0 psi. The actual pressure loss (in pounds per square inch) is a function of the refrigerant used. Horizontal piping should be pitched down in the direction of refrigerant flow (towards the condenser) at a slope of about 0.05 inches per foot (1/2 inch per 10 feet).

Liquid Line Sizing. The size of a liquid refrigerant line is less critical than it is for the compressor suction and discharge lines. The line should be selected so that the total liquid pressure drop does not exceed the equivalent of one to two degrees change in saturation temperature. For R-22, this is equal to 2.2 to 4.6 psi. If the pressure drop is too high, liquid refrigerant may flash to gas and cause faulty thermostatic expansion valve operation.

Flashing can also be a problem in vertical liquid piping when the evaporator is higher than the condenser. Liquid refrigerant leaving the condenser is under a static head from the column of liquid in the riser. As liquid refrigerant moves up the pipe, static pressure decreases, increasing the risk of flashing. Refer to the manufacturer's recommendations for liquid lift when designing split systems with the evaporator higher than the condenser.

The total liquid pressure drop must include the loss through piping, fitting, and accessories such as solenoid valves, driers, and strainers. Horizontal piping should be pitched down in the direction of refrigerant flow (towards the evaporator) at a slope of about 0.05 inches per foot (1/2 inch per 10 feet).

Suction Line Sizing. Standard practice is to limit the total pressure drop in the suction line to the equivalent of about 2 degrees change in saturation temperature. For R-22, this is equal to 2.9 psi at 40°F suction temperature. If the pressure loss to too large, the compressor is forced to operate at a lower suction pressure to maintain the desired evaporator temperature.

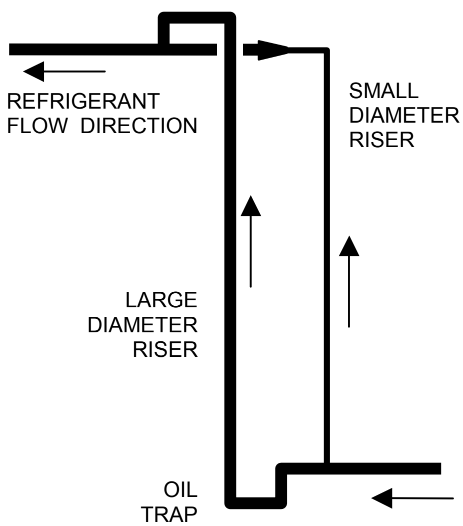

Figure 2. Typical Double Riser Arrangement

Oil entrainment is an important consideration in suction piping design. Gas velocity that is adequate to move oil in a horizontal line may be inadequate to lift oil up a vertical rise. In this case, it is common to reduce the pipe size, thereby increasing gas velocity, but at the cost of higher pressure drop. When the pipe changes back to horizontal, the size is increased to the original size. It is not necessary to change pipe sizes for a vertical drop. Horizontal piping should be pitched down in the direction of refrigerant flow at a slope of about 0.05 inches per foot (1/2 inch per 10 feet). Systems with staged compressors may need to use dual riser piping as shown in Figure 2.

Compressor Protection

To insure reliable compressor operation, proper oil return is the most important factor in designing refrigerant piping. Although the suction piping is sloped to encourage oil drainage to the compressor, the suction lines should be trapped at the evaporator to prevent liquid refrigerant from draining to the compressor during idle periods.

Compressors must be equipped with crankcase heaters to keep the oil temperature at least 20°F higher than the rest of the system. When a system is off, refrigerant always migrates to the coldest part of the system. In winter months, the compressor sump of a condensing unit may be the coldest location. During idle periods, condensed refrigerant will mix with oil in the compressor crankcase. If the system refrigerant charge is large enough, the mixture will actually flood the crankcase. When the compressor starts, the pressure in the crankcase drops rapidly. If the crankcase is unheated, the rapid pressure drop results in violent vaporization of liquid refrigerant. This creates a nearly explosive formation of an oil-refrigerant foam mixture. In hermetic motors, foam vents back through the motor compartment and out into the suction line. The foaming oil and liquid refrigerant mixture is entrained by the refrigerant in the suction line and is *slugged* to the compressor where it can damage pistons and cylinders.

Refrigerant Piping Design References

Four valuable resources to guide sizing and design of refrigerant piping are:

- *Carrier System Design Manual*, Part 3, Chapter 3, Refrigerant Piping.
- Carrier reference manual: *Refrigerant Piping for Split Systems*. Form T200-64, Catalog No. 791-064
- ASHRAE *Refrigeration Handbook* 1998, Chapter 2, System Practices for Halocarbon Refrigerants.
- Carrier E20-II HVAC Program Series, Refrigerant Piping Design.

Heating Equipment

Air handlers for use in split systems can be equipped with a variety of optional heating systems: electric resistance coils, indirect-fired natural gas, hot water or steam coils, and air-to-air heat pumps.

WHY USE A SPLIT SYSTEM

Advantages

The widespread use of split systems is an affirmation of their advantages. Foremost, they are flexible, providing many possible solutions to commercial and industrial design challenges. They are simple, reliable, and offer superior performance. Also, split systems are economical, providing an advantageous balance of first cost and operating cost.

Flexibility

Flexibility is the overriding advantage of a split system. Because a split system is made up of multiple components that are connected through a custom designed refrigerant piping system, the engineer has a large variety of possible solutions available to meet architectural and physical requirements.

- The evaporator coil can be factory-installed as part of a packaged air handler or as part of a built-up air-handling unit.
- The air handler can be located anywhere in the building (within refrigerant piping length limitations).
- The condensing unit can be located outdoors where it can be architecturally concealed or, at a minimum, where it will cause the least disruption to the building's aesthetic environment.
- The condensing unit can be located on the roof or on the ground adjacent to the building.
- Split systems can be installed in multi-story buildings. In most applications, the buildings are one-, two-, and three-story structures. Buildings up to six stories have been successfully served with traditional split systems. By applying special design features, the requirements of taller buildings can also be met.
- Condensing units and air handlers are built in a variety of sizes and configurations. Commercial condensing units are available in sizes between 6 and 130 tons. Packaged air handlers vary in size from 6 to 30 tons. At the large end, central station air handling units are available in sizes up to 125 tons.
- The ability to mix-and-match combinations of air handlers and condensing units enables the building designer to select equipment precisely matched to the facility's heating air-conditioning loads.
- Using multiple systems enable cooling and heating to be divided into defined building zones.

Simplicity

Split systems are among the simplest of systems available for commercial applications. Chilled water systems are significantly more complicated, have more components, require more maintenance, and cost more to install than split systems. Packaged rooftop systems are simpler in that there is only one major component to install, but they lack the flexibility of a split system.

An air-handling unit for a split system is typically located close to the air-conditioning load. This enables air distribution using the minimum amount of ductwork and fan energy. It also permits buildings to be zoned on a floor-by-floor basis, eliminating the need for large vertical duct chases and fire dampers.

Split systems do not require large penetrations through the building walls or roof. Packaged systems, either roof- or grade-mounted, must have large penetrations for ductwork.

Reliability

Split system components are mature products with long manufacturing and development histories. The 1999 ASHRAE HVAC Applications Handbook lists the following median service lives for split system components:

Air-cooled condensers	20 years
Reciprocating compressors	20 years
Centrifugal fans	25 years
DX coils	20 years
Air-to-air heat pumps	15 years

Although the above service time is less than is expected for central chilled water systems, it is longer than the 15 year median life quoted by ASHRAE for packaged rooftop systems.

Performance

Typical Energy Efficiency Ratios (EER) for condensing units range from 10.2 to 11.8 at ARI standard conditions. When installed as a system, typical EER values for the condensing unit and air handler operating together range between 8.7 and 10.0.

As a comparison, standard-efficiency packaged rooftop air-conditioning units have typical EER values between 8.7 and 9.7. Depending upon the manufacturer, high-efficiency rooftop units may have EER values as high as 9.3 to 11.5.

Cost

Energy consumption of a split system (on a kW per ton basis) is higher than a large central water chiller. But, for a single building with a total peak load less than 100 tons, a series of multiple split systems may have a life cycle cost advantage. The building designer must thoroughly evaluate all pertinent installation, operating, and maintenance costs to make an informed decision. Although a central water chiller, by itself, may use less energy on a per-ton basis, pumps, cooling towers and other energy consuming equipment, support it. Simply stated, split systems typically cost less to install and maintain.

Disadvantages

The benefits of a split system engender several disadvantages:

- Propeller fan(s) used in the condensing unit can be a relatively loud noise source that may require special consideration depending on the application. Carrier offers low-sound packages that attenuate radiated noise.
- Because the air handling equipment is distributed throughout a building, consideration must be given to acoustics and noise conduction through relatively short ducts to the conditioned spaces.
- Air handling equipment near the center of the building requires special provisions to admit outdoor air. Units with economizer cycles must usually be located near an outside wall.
- Return fans are rarely used with split systems, forcing the designer to minimize return ductwork.
- An element of care is necessary to design refrigerant piping, especially for long piping runs. Improperly designed piping can cause the system to lose capacity. At worst, improperly designed piping can cause compressor failure.

SPLIT SYSTEM APPLICATIONS

Split systems may be applied to industrial, commercial, and residential comfort-cooling applications. Quite often, split system equipment is also used for manufacturing and process cooling applications. Popular applications include: office buildings, commercial or public buildings, retail shopping, manufacturing facilities, churches and other places of assembly, small health care facilities, and schools.

Split systems are used in retrofit applications to supplement areas of inadequate service by a building's existing central system. Hospitals, medical facilities, and buildings that have been remodeled or adapted to a new use frequently install supplementary split systems. The rapid pace of technology, evolving business methods, and economic growth push old buildings into new uses. Split systems are an excellent complement to the limitations of an existing central air-conditioning system.

Air-cooled split systems are ideal for any location where the availability of water is limited, or the use of water is restricted for conservation or health reasons. Even if water is not restricted, any facility that benefits from avoiding the capital, maintenance, and operating costs of water-cooled systems is a suitable application.

Equipment Combinations

Because split systems are assembled from multiple components, the ability to mix-and-match pieces to fit a particular situation adds a great deal of flexibility. Systems can be air-cooled or water-cooled and configured as:

- Cooling only
- Cooling with supplementary heating (installed in the air handler)
- Heat pump system
- Chilled water using a shell-and-tube evaporator

Multiple Unit Systems

When it is impractical to use a single split system for a building, or if zoning is necessary to insure uniform comfort, multiple systems are commonly used. Zoning is achieved by serving a group of rooms with similar heating and cooling load characteristics with a separate unit. Because of the many unit sizes and combinations available, multi-unit systems can be matched to the unique combinations of sensible and latent loads in each zone.

Buildings with multiple tenants benefit from split systems because they permit zoning the building by tenant areas. This eliminates conflicts between tenants and allows the landlord to segregate energy usage by individual user. From a conservation standpoint, separate zoning of tenant spaces also enables the building to use setback controls for spaces with occupancy schedules different from other parts of the building. Typical multiple-tenant commercial buildings include:

- Shopping malls
- Small retail centers
- Office buildings
- Industrial parks

Apartment buildings are considered residential, not commercial.

Variable-Volume Airflow

Variable-volume airflow for room temperature control is generally achieved by using bypass terminals that recirculate surplus supply air through a ceiling plenum. This permits the use of constant-volume evaporator fans and is a reliable and more easily controlled system than variable-volume fans. Actual variable-volume fan operation is possible by installing special control accessories.

CARRIER EQUIPMENT

Individual product data is available for commercial split system components:

- Condensing units – 38AK, AKS, and AH.
- Air handlers – 40RM packaged air handlers, 39 Series for large central station applications, and 28 Series for small systems and furnace applications.
- Chillers (heat exchangers) – 10RT.
- Heat pumps – 38AQS matched with 40RMQ packaged air handlers.

KEY SPECIFICATION ITEMS

From a sales perspective, certain features of split system equipment are important to insure the customer gets a quality system and to distinguish Carrier from its competitors.

Condensing Units

- Unloading capabilities of semi-hermetic compressors provide energy savings and promote the system’s ability to precisely match the building load. At a minimum, compressors should have 100% and 67% capacity stages with an option for 33%.
- Semi-hermetic compressors are repairable. If a fully hermetic compressor is failing or failed, it must be replaced.
- Performance (EER) must be certified in accordance with ARI standards.
- Compressor protection features: anti-short cycling protection, high- and low-pressure

switches, oil-level sight glass, and crankcase heater.

- Corrosion-resistant construction options for the condenser coil. Carrier is unique in the marketplace to have four optional construction alternatives, each with an increasing degree of protection.
- Variable speed operation of the condenser fan to permit low ambient operation down to -20°F.

Air Handlers

- Dual-circuit, direct-expansion cooling coils with capacity control valves help maintain humidity control at part-load conditions in units with multiple compressors.
- Tuf-Skin Rx™ insulation installed on the air handler cabinet interior is water and dirt resistant and contains an EPA registered immobilized anti-microbial agent that effectively reduces the growth of bacteria and fungi. It also decreases internal airflow resistance and is a low-cost substitute for double-wall systems.
- Carrier's factory-installed and tested UV-C Germicidal Lamp accessory is unique within the industry. UV-C lamps have been proven effective in killing fungus, mold, and microorganisms in the drain pan and on the face of the evaporator coil. UV-C also offers an energy benefit by keeping the coil free of biological growth than can diminish unit performance.
- Thermostatic expansion valves on direct-expansion coils improve reliability, simplify maintenance, and enhance energy efficiency at part-load conditions.
- Air handlers that can be installed in either the vertical or horizontal position without modification simplify design and installation.
- An economizer option is important for energy savings.
- Carrier leads the industry with Demand Controlled Ventilation and the ability to regulate outdoor airflow based on CO_2 levels in the occupied space.
- Air handlers must be constructed with a pitched, corrosion-resistant drain pan to meet the requirements of ASHRAE *Standard* 62-1989 (1999).
- Factory-installed options for an alternate motor, and both medium- and high-static drives improve the air handler's capacity to perform properly within ductwork and distribution limitations.

RULES OF THUMB

When considering split system applications, remember the following rules of thumb:

- Supply airflow (evaporator flow) should be between 300 and 500 cfm per ton.
- Equipment costs (on a $/ton basis) are minimized for units with the largest capacity within a given chassis size.
- Equipment costs (on a $/ton basis) are highest for units with the smallest capacity within a given chassis size.
- Condensing units and air handlers are matched to nominal sizes. They are also matched and tested to one size smaller and one size larger. For instance, a 15-ton condensing unit is designed, matched and tested with air handlers rated at 12.5 tons, 15 tons, and 20 tons. This provides a total cooling capacity range of 12.5 tons to 17.8 tons with literally dozens of possibilities in between.
- Unequal condensing unit and air handler combinations outside the one-up-and-one-down rule of thumb are possible. In these cases, selection assistance is available from Carrier Application Engineering.

APPLICATION TIPS

The following excerpts are taken from Carrier's publication titled, *Application Tips: Commercial Split Systems*.

Refrigerant Lines: All refrigerant lines should be as short as possible. Liquid line solenoids are always a good idea, but mandatory in applications with line lengths in excess of 75 feet. Line lengths greater than 100 feet should be reviewed with Carrier Application Engineering.

Low Load Conditions: There are two methods by which the refrigerant system can be safely operated at low loads, compressor unloading and hot gas bypass (HGBP). Certain localities limit the use of HGBP by code or legislation. Compressor unloading may provide adequate capacity reduction without using HGBP.

100% Outdoor Air Applications: The control system should be based upon the supply air temperature (downstream of the air handler) and the space temperature. A simple thermostat in the space will not be adequate.

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