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SYNOPSIS

AN HVAC NEWSLETTER FOR BUILDING OWNERS AND MANAGERS

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Part-Load Control Strategies for Packaged Rooftop Units

As a building owner or manager, one of your many challenges is to optimize your HVAC equipment to provide consistent occupant comfort, while maximizing efficiency to conserve energy and contain costs. The more time spent in the design phase analyzing specific conditions for your building, the more appropriate your equipment selection will be. This issue of *Synopsis* discusses the options for packaged rooftop units and controls. A better understanding of these options will allow you to better assess your needs and make the choices that will ensure your energy dollars are wisely spent.

One of the most common mistakes made in HVAC equipment selection is to size the heating and cooling unit(s) to handle the total building load at design weather conditions. Most designers use this method. Yet the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) estimates that design condition (based primarily on dry bulb temperatures) actually occurs only $2\frac{1}{2}$ to 5% of the time each year.

One of the most common mistakes made in HVAC equipment selection is to size the heating and cooling unit(s) to handle the total building load at design weather conditions.

Actual dry bulb temperatures for your location can be analyzed using a bin hour profile. A bin is simply a five-degree range of temperatures. The profile is a chart showing how often (in number of hours) each bin is likely to occur in a year. Most bin hour profiles demonstrate

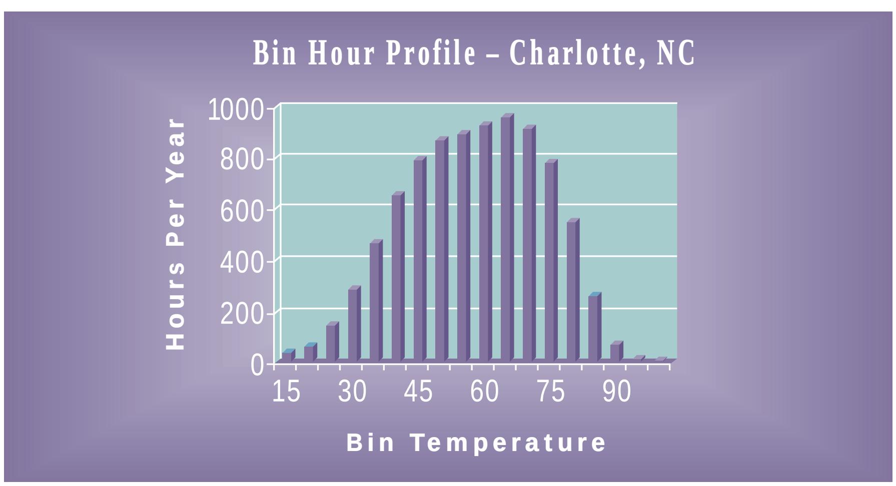


FIGURE 1

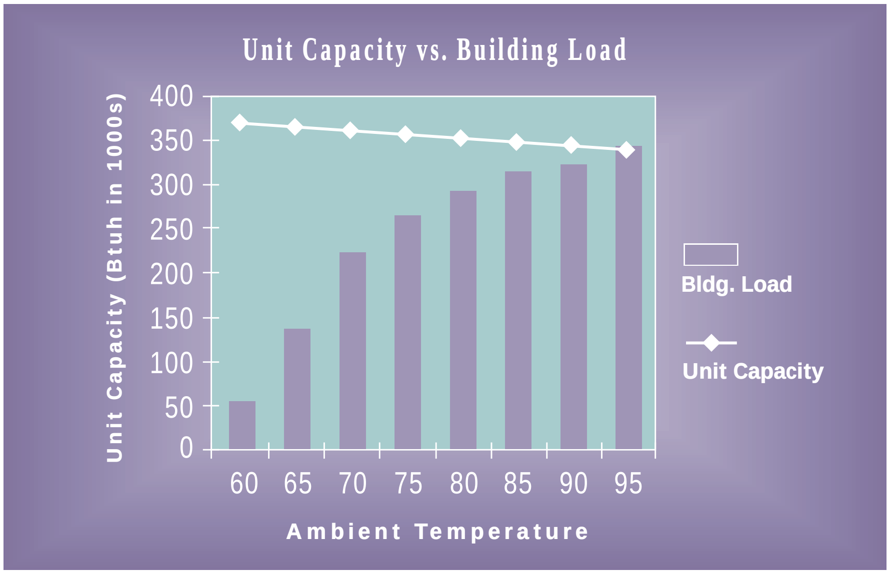


FIGURE 2

that the calculated design temperature for a given area actually occurs infrequently – in other words, most operating hours throughout the year are at off-peak temperatures.

Figure 1 shows a bin hour profile for Charlotte, NC. As you can see, during most hours of the year, the dry bulb temperature is between 45 and 75°F. Yet the design temperatures for Charlotte are 15°F in winter and 95°F in summer – temperatures that rarely occur.

Dry bulb temperature tells only part of the story of a location's climate. Wet bulb temperatures should also be taken into consideration, especially in typically humid areas of the country and applications with large amounts of outside air. Recognizing the importance of this, ASHRAE now publishes a table indicating design wet bulb, as well as the corresponding dry bulb, temperatures. The corresponding values are called "mean coincident" and represent an average dry bulb temperature at each wet bulb temperature.

Building Load Vs. Capacity

Because actual temperatures rarely follow design temperatures, a more complex analysis is required. It is critical to perform an evaluation that will predict the interaction between your building's heating and cooling equipment and the building load under changing conditions throughout the year.

If a rooftop unit is sized for the design condition, when the ambient temperature is below this condition the building load decreases, while the full-load capacity of the rooftop equipment actually increases (see Figure 2). In fact, at temperatures below design condition, most equipment has excess capacity. Buildings with oversized equipment tend to be cold and clammy. During the On cycle, these systems tend to blast large amounts of very cold air, which satisfy thermostats quickly and cycle the units off. During the Off cycles, the inactive cooling coil is performing no dehumidification, causing the space to become uncomfortably humid.

Improperly sized equipment can only create problems, and will ultimately result in higher operating expenses.

The challenge is to properly control the packaged rooftop unit so that it can handle peak design cooling loads and still maintain indoor comfort during the non-peak times of the year. There are many factors to consider in choosing a system that will provide this delicate balance.

Equipment Sizing

Designers tend to be more conservative than necessary in sizing HVAC equipment. An accurate cooling load analysis is all that is necessary to select the proper size unit(s). But many designers perform this analysis and then "throw in" extra factors for a margin of safety – and then sometimes choose the next larger unit as well! This ultra-conservative approach only results in grossly oversized equipment that greatly magnifies the load/capacity problems discussed previously.

Oversized units not only pose extreme control challenges, but they can also result in indoor relative humidity levels of more than 60%. This kind of humidity provides an ideal environment for microorganisms and has been linked to indoor air quality (IAQ) problems, such as "sick building syndrome." In addition, oversized equipment often causes undesirable noise levels as well as drafts.

Improperly sized equipment can only create problems, and will ultimately result in higher operating expenses. Fortunately, there are several load estimating software programs available. These easy-to-use programs are a valuable tool for the designer, accurately and quickly calculating building loads and appropriately-sized HVAC equipment.

Zone Considerations

Your building's layout will dictate how many heating/cooling zones there are. This, in turn, will affect whether the building is best served by a single large rooftop air conditioning unit, or several smaller units providing individual control of specific zones. Additional factors to consider in deciding how many units to use include:

- Economics
- Available Space
- Unique Load Profiles
- Minimum Loads
- Control Requirements
- Local Zoning Regulations

System Types and Controls

Constant Volume Systems

The simplest rooftop system is a constant volume system serving a single zone, which may vary in size from 500 to 50,000 square feet. Constant volume means that the supply airflow from the rooftop unit is distributed at a constant rate at all times (airflow is measured in CFM, or cubic feet per minute).

These systems are usually controlled by a single thermostat, turning the unit on when heating or cooling is required, and off when the space is within one or two degrees of the desired setpoint.

Constant volume systems often use at least two "stages of cooling" to further control the conditioning of the space. The advantage of staging the rooftop unit's compressors is that at part-load conditions, only part of the unit's cooling capacity is used. This prevents excessive On-Off cycling and wide swings in indoor temperature and humidity. Two-stage cooling is often accomplished by having two independent refrigerant circuits within the rooftop unit.

The advantage of staging the rooftop unit's compressors is that at part-load conditions, only part of the unit's cooling capacity is used.

Another way that the rooftop unit's capacity is reduced to match varying building load conditions is reduction in compressor capacity as the building load becomes satisfied. As the building cools down, the return air temperature to the unit's evaporator coil drops, causing a corresponding drop in refrigerant temperature and pressure. As the refrigerant pressure decreases, its density also decreases, causing the compressors to circulate a smaller amount of refrigerant through the system.

Some large packaged rooftop units use multiple compressors on each refrigerant circuit. This allows for more than two stages of cooling, thus controlling capacity even more precisely. The more stages of capacity a system has, the more closely it will be able to match the building's fluctuating load without excessive On-Off cycling. Adding stages, however, requires more sophisticated control schemes or thermostatic control to allow for the multi-staging of the compressor.

For example, a unit could have two independent refrigeration circuits with two compressors on each circuit. Since commercial thermostats rarely have more than two stages of control, an alternate method – sometimes called a "controller" – is needed to cycle these compressors to obtain the four stages of capacity available. One method would be to use an integrated controller that communicates with a space sensor instead of a wall-mounted thermostat. A time-delay device is often built into these controllers to provide at least five minutes between On and Off cycles, preventing rapid and excessive compressor cycling.

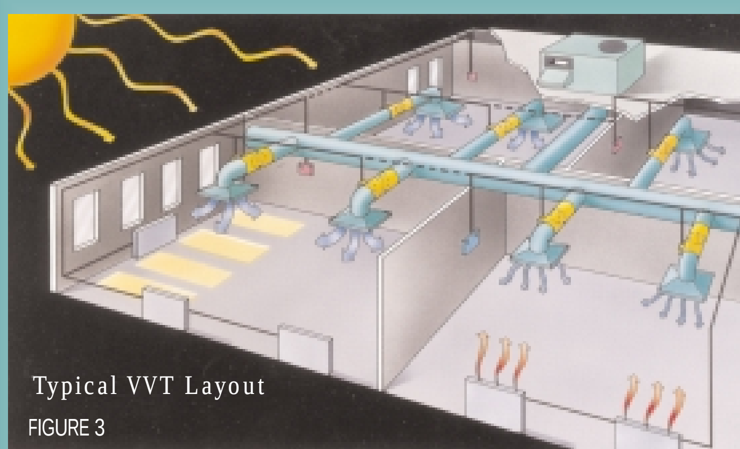
Another capacity control device used on constant volume units is a suction pressure unloader. Designed for semi-hermetic compressors, this control prevents refrigerant gas from entering the compressor cylinders when suction pressure drops, as it does under low building load conditions. Thus, the compressor cannot cycle on. These unloaders can be used with standard two-stage thermostats and need no external controls. Each stage of the thermostat controls one of the rooftop unit's refrigerant circuits. Suction pressure unloaders can be configured to allow for as many as six or more capacity stages, greatly improving the unit's response to building load conditions without excessive On-Off cycling.

Variable Airflow with Constant Volume Rooftops (VVT Systems)

A VVT system also uses a constant volume rooftop unit, but serves multiple control zones (areas within the building, each served by a single thermostat). VVT systems use a monitor thermostat, zone thermostats, zone dampers and bypass dampers to control airflow in the building to match each zone's requirements (see Figure 3).

The monitor thermostat is the central traffic controller of the system. Through "polling" of the zone thermostats, it detects heating or cooling requirements and sends a signal to start the rooftop unit and supply conditioned air to the zones.

A zone thermostat is located in each control zone and is connected to a modulating zone damper, located in the branch duct leading to the zone from the main trunk duct. As the rooftop unit supplies air into the trunk duct, each zone thermostat modulates its damper to a more open or closed position, depending on the needs in the zone.



Typical VVT Layout

FIGURE 3

The bypass damper is located near the rooftop unit. Its job is to modulate open as the individual zone dampers close, allowing excess airflow and duct pressure to flow into the return air side of the unit. This bypass arrangement maintains constant airflow through the rooftop unit. It also ensures that a minimum amount of air (and thus heat load) is being applied to the rooftop cooling coil at all times, preventing refrigerant from flooding back to the compressors. When the monitor thermostat detects that all zone thermostats are satisfied, it sends a signal to turn the rooftop unit off.

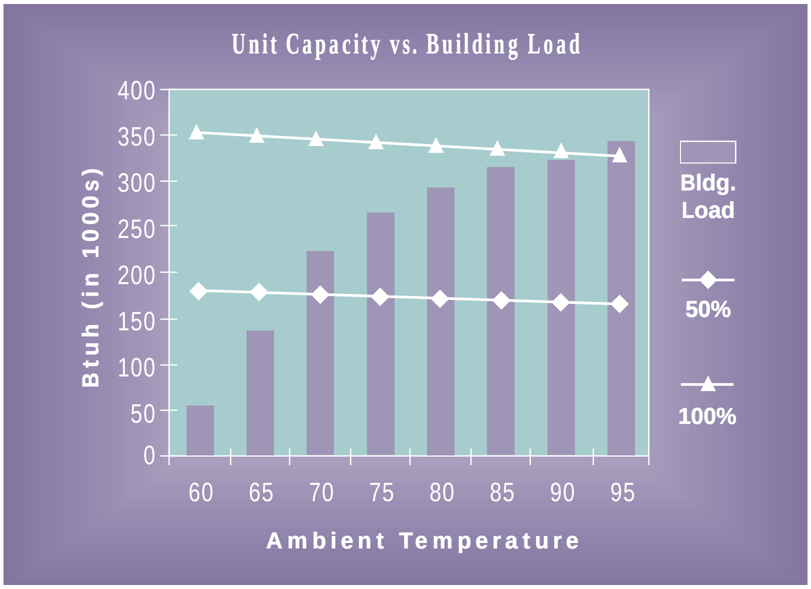


FIGURE 4

VVT systems often use continuously operating fans to circulate air throughout the building at all times. This improves occupant comfort and also tends to stabilize building temperatures. These systems also benefit greatly from multiple-stage capacity control. This is especially true for systems with rooftop units larger than 15 tons, serving larger zones. Larger areas tend to have more load variables (occupancy, solar gain, transmission gains, etc.) and more fluctuation in zone requirements, making it more difficult for the rooftop unit to match changing conditions. Multi-staging in these systems contributes to equipment reliability – by preventing refrigerant floodback – as well as to occupant comfort.

VAV systems are often an attractive choice to use with packaged rooftops for economic reasons.

Variable Air Volume (VAV) Systems

VAV systems are often an attractive choice to use with packaged rooftops for economic reasons. First costs and installation costs are lower, and the required floor space is less than with other systems, freeing up leaseable square footage.

These systems serve multiple zones within a building, supplying a varying amount of air at a constant supply air temperature. The quantity of air supplied is regulated in one of two ways – using a variable frequency drive (VFD) to change the speed of the fan or using inlet guide vanes to change the flow characteristics of the fan wheel itself.

Each zone in a VAV system has its own thermostat, which controls a damper, or "VAV box." The damper opens and closes in response to the thermostat, varying the airflow to maintain the zone setpoint.

VAV boxes may supply heat in various ways to allow for some zones in the building to be heated while others are being cooled. VAV boxes can contain heat sources, such as electric resistance strip heaters or hot water coils. Or they can be equipped with fan powered mixing boxes to supply heat. During the heating cycle, the primary air damper closes to a minimum position and the fan and heating coil are energized to provide heat to the zone. This minimizes the requirement for "reheating" of the cooled supply air, which is an expensive and wasteful way to achieve simultaneous heating and cooling in a building, and is often prohibited by building codes.

There are some significant differences between VAV and VVT systems. In a VAV system, the quantity of supply air flowing across the rooftop unit's cooling coil actually decreases at part load – it does not use a bypass damper to redirect air to the return duct.

In addition, most VAV rooftop units are not turned on and off by a thermostat; they are started and stopped by a time clock, programmed for occupied and unoccupied modes of operation. In fact, unlike constant volume systems, VAV systems do not normally cycle on and off during the day, or other occupied times. This means VAV rooftop units must have the ability to operate over a wide range of loading conditions, from full load to very low load and everything in between. It is therefore advantageous to equip a VAV unit with as many capacity stages as possible. The most common forms of capacity staging are compressor cycling and compressor cylinder unloading.

As previously discussed, cycling compressors involves simply turning individual compressors on and off.

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WHAT IS MEANT BY BUILDING LOAD?

Building load is the demand created in a building space for heating or cooling to achieve setpoint temperatures – either programmed or manually set. Building load varies throughout the year as climate conditions change. In addition to outdoor temperature and humidity, the following factors also affect building load:

- Lighting systems
- Miscellaneous electrical demands, such as office equipment, alarm systems, elevators, etc.
- Occupancy, i.e., the number of people in the building
- Ventilation (ASHRAE Standard 62-1989 requires 20 CFM of outside air per person)
- Wall R value
- Roof R value

Computer software is helpful in precisely calculating your predicted building load.

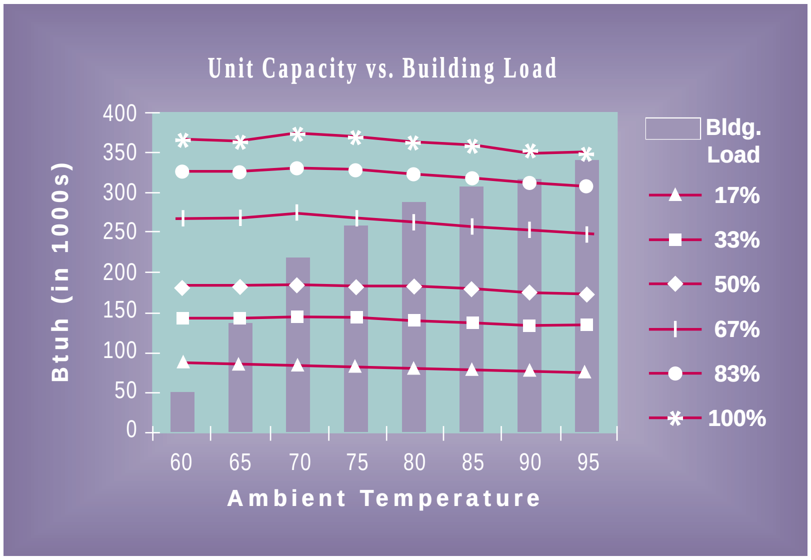

FIGURE 5

This can be an efficient method of capacity control. But this method is only effective if the unit has enough compressors to adequately change its capacity as the building load changes. Otherwise, excessive compressor cycling and poor temperature control may result.

Figure 4 illustrates the capacity of a 30-ton rooftop unit with two 15-ton compressors versus the building load at various temperatures. The "gap" or mismatch evident on the chart means that the compressors are cycling intermittently and frequently, which may result in accelerated wear and tear on the compressors. And since they are not really matching the building load, unacceptable swings in indoor temperature and humidity will probably result as well.

Cylinder unloading is a popular method of increasing capacity staging, while minimizing compressor cycling. Cylinder unloaders close internal passageways of the compressor to prevent compression and thereby reduce the flow of refrigerant. One of the benefits of cylinder unloading is that the discharge air temperature remains constant, helping to control humidity in the building. Cylinder unloading allows for multiple compressors and up to six stages of capacity. Figure 5 shows how much more closely the same 30-ton rooftop unit can match the building load, when it is configured for six stages of capacity. This unit's compressors are cycling much less frequently, improving performance and providing much better control of the building's environment.

When selecting VAV rooftop units, it is also important to consider low load conditions. The minimum possible capacity stage of the unit (found in manufacturers' catalogs) should be compared to the anticipated minimum building load (calculated using load estimation software). A minimum capacity stage lower than the minimum building load will prevent problems such as evaporator coil icing, low suction pressure and refrigerant floodback.

Cylinder unloading is a popular method of increasing capacity staging, while minimizing compressor cycling.

If the minimum capacity stage is not as low as the minimum building load, "hot gas bypass" may be used. This is a common – although energy inefficient – method of keeping the unit operating when cooling requirements are critical. It involves routing hot refrigerant gas from the refrigerant compressors directly to the evaporator coil, to elevate suction temperatures and reduce the unit's capacity. A more efficient solution to a unit running frequently in hot gas bypass mode is a system using multiple VAV rooftop units.

Another possibility for energy-efficient low load control, available on some rooftop units, is to have the discharge air controller actually cycle the last stage of compression based on discharge air temperature. This method allows accurate discharge air control all the way down to virtually no load, without the use of hot gas bypass. This type of control is based on supply air temperature and is not a coil or suction frost sensing routine – thus, it is a control scheme and not merely a safety mechanism.

Conclusion

Choosing the right packaged rooftop system involves careful analysis of your building, as well as comprehensive evaluation of the system's performance under varying load conditions. While your equipment must be able to respond to peak loads, accurate assessment will ensure that it is not oversized for your building's needs. And a thorough understanding of part load conditions and the many control options available to respond to them will help you to enhance performance, maximize equipment life, improve occupant comfort and contain your energy costs.