SAV™ (STAGED AIR VOLUME) SYSTEM – TWO-SPEED FAN CONTROL STRATEGY FOR PACKAGED ROOFTOP UNITS

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INTRODUCTION

Packaged rooftop units represent the largest segment of unitary equipment for small commercial applications in North America.[1] Historically this product design has used a constant volume indoor fan system to provide cooling, heating and ventilation to the commercial space.

Recently, the concept of SAV™ (staged air volume) systems on packaged rooftop units has been introduced. An SAV system saves energy by automatically adjusting the indoor fan motor speed in sequence with the unit's cooling, heating, and ventilation needs. Studies show that properly controlled indoor fan systems can reduce power consumption of the entire unit by up to 57%[2] when coupled with the proper compressor and unit control system, without sacrificing space conditioning comfort.

First introduced by ASHRAE Standard 90.1-2010 with a scheduled effective date of January 1, 2012, two-speed indoor fan control was written into state code by California's Title 24, and has been mandated by the US Department of Energy (DOE) to be written into enforceable state building codes by October 18, 2013. SAV systems meet all aspects of these code requirements while providing even better energy savings.

This paper will outline the reasons to consider using SAV two-speed indoor fan control in packaged rooftop unit and the application factors that must be evaluated.

STAGED AIR VOLUME (SAV) SYSTEM MEETS CODE REQUIREMENTS AND PROVIDES INCREASED ENERGY SAVINGS

Staged air volume two-speed indoor fan control for packaged rooftop units may be desired for a number of reasons; two of the major reasons are code requirements and energy efficiency. Each of these reasons must be understood fully in order to evaluate the different technological approaches to accomplishing two-speed indoor fan control.

CODE REQUIREMENTS: ASHRAE STANDARD 90.1-2010

Minimum industry standards drive much of what is used by building design engineers, provide the foundation for state and federal codes, and provide direction to equipment manufacturers for product development as well. While these standards set only minimum requirements, and designers are free to go well beyond those minimum requirements, it is common for the minimum requirements to provide a balance of benefits versus increase in cost.

Typical building codes use terminology and language derived from industry standards developed by organizations such as ASHRAE[3] and IBC[4] as well as code language from IECC.[5] These standards have begun to focus on energy efficiency in addition to the traditional concerns of health and safety. Considerations now include reducing the energy consumed by buildings, reducing long term costs for building owners, and reducing CO_2 emissions.

The bedrock standard for Federal and State commercial building codes is ASHRAE Standard 90.1, "Energy Standard for Buildings Except Low-Rise Residential Buildings." ASHRAE Standard 90.1 is generally updated every three years (recent editions were released in 2004, 2007, and 2010) with a supplement published every 18 months. After issuance of the standard, states must take the initiative to adopt the language into their local codes. There has been widespread disparity across the country as to which version of 90.1 has been adopted. As of January 1st, 2012, some states and territories of the United States have commercial code language equivalent to or more stringent than ASHRAE Standard 90.1-2010, 2007, or 2004, while some states have no statewide code.

Recently, however, the US Department of Energy (DOE) has mandated that states implement and enforce later versions of Standard 90.1. Once the DOE has determined that the latest Standard version effectively saves energy above and beyond the previous version, they issue a Final Determination. DOE issued a final determination on Standard 90.1-2010 on October 19, 2011.[6] Furthermore, DOE has required that states update their local codes to meet or exceed the requirements of Standard 90.1-2010 by October 18, 2013.[7]

Any engineer designing a system to meet the requirements of ASHRAE Standard 90.1-2010 using a direct expansion rooftop unit or air-handling unit must, under the Mandatory Provisions of section 6.4, use a product that meets the requirements of section 6.4.3.10 (Single Zone Variable-Air-Volume Controls). This requirement states that HVAC systems with cooling capacities of 110,000 btu/h or more shall have variable airflow for indoor fan systems as controlled by a 2-speed motor or variable speed drive.[8] Specifically, at cooling demands less than or equal to 50%, the supply fan shall be able to be reduced to no greater than the larger of the following:

2/3 of the full fan speed,

or

the volume of outdoor air required to meet the ventilation requirements of [ASHRAE] Standard 62.1.

The key item to recognize here is that the fan speed should be reduced when the reduction in the required space cooling load occurs, while ventilation air requirements should not be ignored when the fan speed is changed. Furthermore, the reduction is for cooling and ventilation modes only.

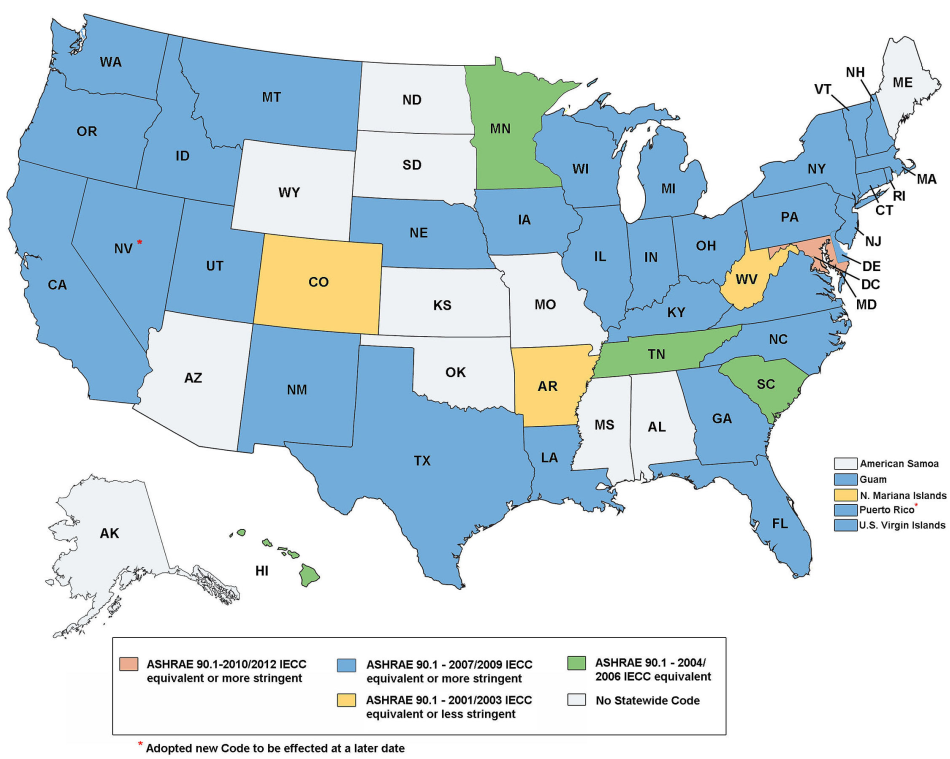

Fig. 1. Status of Code Adoption: Commercial; as of January 1, 2012

(Source: US Department of Energy, Building Energy Codes Program; http://www.energycodes.gov/states/maps/commercialStatus.stm)

ENERGY EFFICIENCY

The use of two fan speeds for energy efficiency is a simple idea. Historically, direct expansion packaged rooftop units have used a constant volume fan system that is controlled by a signal from the building space (via a thermostat or space sensor). These fans operated continuously and at a fixed speed during the occupied mode of the building system. It is important to note that this differs from a residential application where the system fan is allowed to cycle based on the cooling or heating demand. Commercial applications require the fan to run continuously due to the requirement for ventilation air to be continuously introduced to the conditioned space during the occupied period. Therefore, while many of these indoor fan motors may be of a fairly small size (less than 5 hp) the fact that they operate continuously offers a tremendous opportunity for energy savings.

The SAV™ system concept utilizes the full fan speed (100% operation) for the design load requirement, but then reduces the fan speed when the load does not require the full design cooling capacity. Since full load conditions are only experienced for a small percentage of the total cooling hours of operation, the majority of the fan operation will be at a lower speed, therefore consuming less power and thus lowering energy usage. Figure 2 shows the difference in power consumption (constant volume vs. staged air volume) of the total cooling system for a 10-ton Standard Efficiency (ASHRAE 90.1-2010 Federal Minimum) Rooftop Unit, equipped with airside economizer. Figure 3 shows this difference as the percentage of energy savings achieved by the two-speed staged air volume unit compared to the constant volume fan unit. Figures 4 and 5 continue the demonstrations for a similar 20 ton unit.[9]

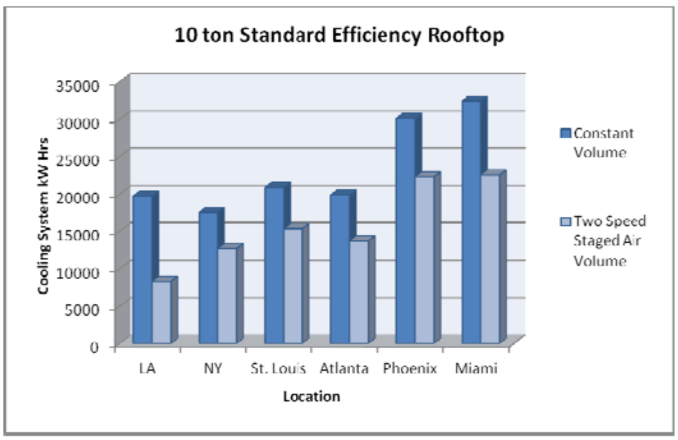

Fig. 2. Power Consumption of 10-Ton Standard Efficiency Rooftop Unit

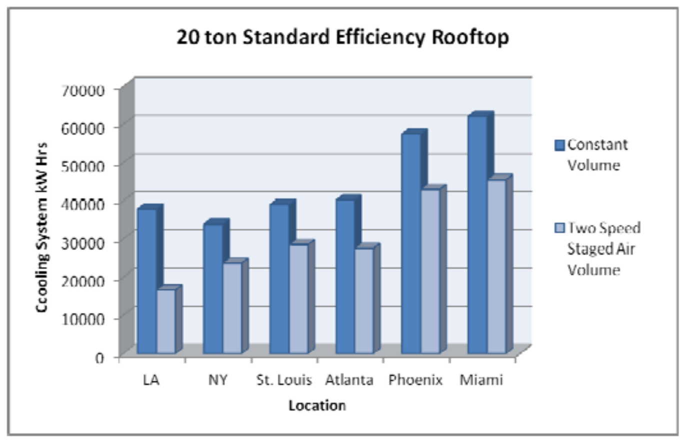

Fig. 4. Power Consumption of 20-Ton Standard Efficiency Rooftop Unit

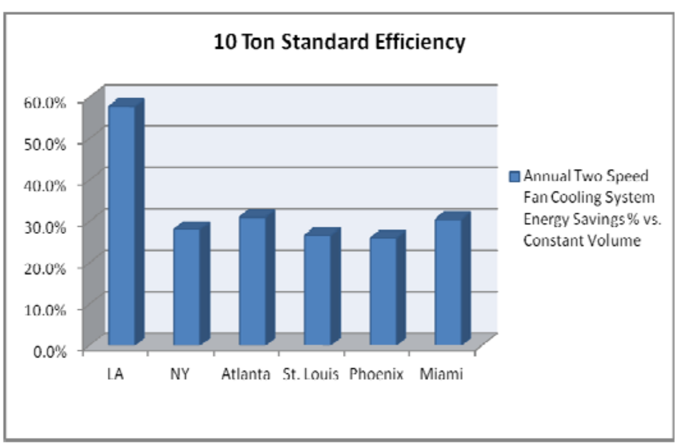

Fig. 3. Annual % Savings of Two-Speed Fan Cooling System Compared to Constant Volume System (10-Ton Unit)

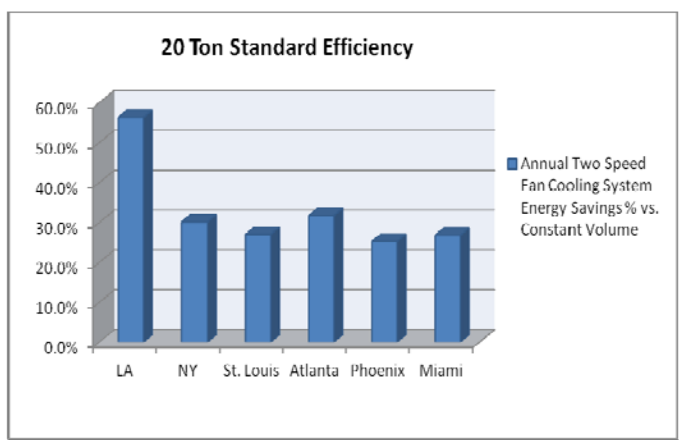

Fig. 5. Annual % Savings of Two-Speed Fan Cooling System Compared to Constant Volume System (20-Ton Unit)

APPLICATION CONSIDERATIONS

EFFECTS OF MULTI-SPEED FAN OPERATION ON VENTILATION

Conventional ventilation air devices for direct expansion packaged rooftop units assume a single-speed fan operation. This assumption applies to devices such as manual outdoor air dampers, two-position dampers, economizers and demand controlled ventilation (DCV) systems. Therefore, when utilizing a two-speed fan operating strategy, additional design complexity must be considered or else the system will not function as desired. For example, a manual damper or two-position damper is typically adjusted once, during the unit installation, and set for a single set of static pressure conditions to allow a specific amount of outdoor air to be drawn into the building's HVAC system as ventilation air. This works well when the rooftop unit has a fixed airflow, but in a two-speed scenario, the ventilation device will either provide over-ventilation or under-ventilation. Over-ventilation occurs when the device is set for the ventilation airflow at the lowest fan speed – when the fan increases to a higher airflow set-point, then more outdoor air will be drawn in, increasing the load on the unit compressors or heating system and resulting in higher energy consumption with potentially undesirable space conditioning effects. Conversely, under ventilation exists when the ventilation device is set based on the highest fan speed (the 100% operating point); when the fan is reduced to a lower speed then the amount of ventilation air will drop as well and will be below the minimum amount required by code.

The same situation exists for traditional economizers and for DCV systems – if the device or system only has one set of operating points (e.g., a minimum ventilation position) then either under-ventilation or over-ventilation will occur as the fan changes speeds.

Therefore, when utilizing a two-speed indoor fan, the system must include as many different sets of ventilation operating points (e.g., ventilation positions) as the fan has speeds. Said differently, the economizer must be able to adapt to varying fan speed in order to maintain a consistent minimum outdoor air ventilation rate. For a staged air volume system with two fan speeds, this is fairly simple due to the limited number of additional operating points, although the system still requires a different control package than a standard constant volume rooftop package.

EFFECTS OF MULTI-SPEED FAN OPERATION ON DUCT AND DIFFUSER DESIGN

Another factor to consider is the effect that changing rooftop unit fan speed operation will have on the system ductwork and diffusers. If any of the fan speeds are too low for the diffusers being used, air mixing will be affected, and cold-air dumping or other undesirable effects can occur. Similarly, a fan speed that results in airflow that is too high for the selected ductwork may result in undesirable conditions such as noise due to high air velocity.

Therefore, when considering a staged air volume two-speed fan strategy, it is important to select ductwork and diffusers that are compatible with the full range of airflows that will be seen from the HVAC unit. In conducting replacement or retrofit applications, the space diffusers and/or ductwork may need to be changed to accommodate a new rooftop unit with two-speed fan operation.

FAN CONTROL STRATEGIES

CONSTANT VOLUME FAN OPERATION

Conventional constant volume direct expansion packaged rooftop unit indoor fan operation is very simple: The unit fan comes on when in the occupied mode and is allowed to cycle only when in the un-occupied mode. Typically, this is controlled by a commercial space thermostat with occupied and un-occupied set points. Even when using a direct digital controller (DDC) device, the unit fan still operates in the same manner. The indoor fan is controlled by either a belt drive motor system or a direct-drive fan, both of which have been configured for a single fan speed.

SAV (STAGED AIR VOLUME) TWO-SPEED FAN OPERATION

In a staged air volume two-speed fan strategy, the unit fan must be able to operate at two discrete fan speeds. There are three main ways to accomplish this: a traditional belt drive single-speed motor controlled by a variable frequency drive (VFD), a two-speed motor that has two sets of windings, or a direct-drive motor (PSC or ECM) controlled by relays or a digital control system.

A VFD changes frequency to change the speed of the motor; this requires that the motor's bearings be able to support operation at less than the 60 Hz design speed. The cost of VFDs is low to moderate, they can be pre-programmed to specific speeds while allowing manipulation in the field, and they are highly efficient. In addition, they can be sized to any motor horsepower requirement and can provide additional functionality such as ground fault and mis-wiring protection. Because of their electrical construction, VFDs provide a ramp-up speed that typically takes 10 to 30 seconds; this automatically "soft starts" the indoor fan, thereby avoiding starting jolts that create excess noise and mechanical wear on the system. The main drawbacks of

VFDs are their physical size compared to the two alternatives and, in the case of some VFDs, the potential for a complex controls system.

A direct-drive motor receives a signal from the control system that changes the motor speed. Across the range of direct-drive motor options, price varies along with efficiency. The application flexibility of the motor is typically limited, as the functionality must reside in the controls of the base unit. The direct-drive motor takes up no additional space in the base rooftop and can be field configured through the base unit controls. The level of complexity and functionality is highly dependent on the interface, algorithms and design of the base unit controls. Historically, direct-drive motors have had limited horsepower capability, thereby being less attractive for use in applications above 5 tons (2000 cfm).

The two-winding, two-speed motor is the simplest and least flexible of the three options. The motor has two sets of windings: one set is energized for one discrete speed and the other set energized for the second speed. This requires some complexity of wiring on the part of the rooftop manufacturer but considerably less control system complexity. The motor will be slightly larger than a comparably sized single-speed motor. The two speeds of the motor are determined long before the motor arrives at the job site and, because they are a function of the winding design, the speeds are unalterable and cannot be changed in the field. Furthermore, the two-winding motor carries considerable expense, given the inflexibility of the motor's speeds and inability to offer additional application functionality this option though simple is judged to be of lower value than the other options.

An ideal staged air volume two-speed fan system is easy to set up, flexible, covers a wide range of application conditions, does not add undue system complexity and can be acquired at a reasonable cost. The table below provides a summary comparison of two-speed fan systems.

CONCLUSIONS

Two-speed fan control is an ASHRAE Standard 90.2010 requirement that is making its way into state building codes, and for good reason. Whether or not required by a building code, two-speed indoor fan control is desirable because it saves considerable energy on applications that have part load cooling conditions for some portion of the cooling season.

When considering multi-speed fan operation, the effects on ventilation and ductwork and diffuser design must be considered to be sure that code and comfort requirements are met.

There are several methods of achieving two-speed fan operation, and the most appropriate choice may depend on the actual application. However, generally speaking, the SAV™ system with variable frequency drive provides the highest value for the flexibility/cost trade off.

Feature	Variable Frequency Drive	Two-speed / Two-Winding Motor	Variable Speed Direct-Drive Motor
Control System	**Varies**	**Simple**	**Varies**
Lo/Hi Speed Ratio Adjustable	**Yes**	**No**	**Yes**
Cost	**$ to $$**	**$$$**	**$ to $$**
Static pressure capability	**High**	**High**	**Low**
Additional Standard Functionality	**High**	**Low**	**Low**
Soft Start Capability Standard	**Yes**	**No**	**No**

NOTES

[1] Census Current Industrial Report MA333M, July 2011.

[2] 48TC*D12, Standard Efficiency Electric Cooling/Gas Heating 10 ton Rooftop in Los Angeles, CA., based on annual estimated electric energy savings utilizing Carrier's Hourly Analysis (HAP) Program v4.6. Based on cooling and ventilation fan runtime hours using ASHRAE 90.1 office application, default schedule, weather, and building data. 0.10 ($/kWh) energy rate. Los Angeles evaluated with differential enthalpy economizer.

[3] ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers

[4] IBC - The International Building Code (IBC) is a model building code developed by the International Code Council (ICC).

[5] IECC - International Energy Conservation Code®

[6] Federal *Register*, "Building Energy Standards Program: Final Determination Regarding Energy Efficiency Improvements in the Energy Standard for Buildings, Except Low-Rise Residential Buildings, ANSI/ASHRAE/IESNA Standard 90.1-2010", Docket # EERE-2006-BC-0132, October 19, 2011.

[7] Ibid.

[8] ASHRAE Standard 90.1-2010 Section 6.4.3.10 "Single Zone Variable-Air Volume Controls," p. 44.

[9] Data for figures 2, 3, 4, and 5 based on annual estimated electric energy savings utilizing Carrier's Hourly Analysis (HAP) Program v4.6. Based on cooling and ventilation fan runtime hours using ASHRAE 90.1 office application, default schedule, weather, and building data. Carrier model 48/50TC*D12 and 24 at 0.10 ($/kWh) energy rate. All locations except Los Angeles evaluated with a single dry bulb economizer; Los Angeles evaluated with differential enthalpy economizer.

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