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VAV Coils, Fan Coil Devices

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Proper design and specification of VAV terminals or fan coils can be quite challenging as there are many items that must be considered, including perimeter zone needs, motor types, discharge air temperatures, energy consumption, as well as compliance with local codes and current standards. One item in particular seems to make the selection process that much more difficult—the coils. They are specified as a means to heat or cool conditioned air, using either hot or cold water, electricity, or in some cases, direct expansion (DX) coils. Without understanding the parameters for selection, the limitations of the coils and their impact on the air-distribution system, engineers will continue to run the risk of developing faulty designs and problematic installations.

When a heating coil is specified on VAV terminal units, it is typically to deliver individual room controlled heat to perimeter zones and offset skin load heating demands. Single-duct terminals normally reheat cooled primary air to offset perimeter heating requirements. This may waste energy, especially when the same air handler is using chilled air for interior zones, which require year-round cooling. However, ASHRAE Standard 90.1-2013 now allows up to 50% of the design maximum cooling airflow in a VAV terminal to be heated, provided that the minimum is set at 20% of the cooling maximum and that the discharge temperature is limited while heating airflow is varied. Fan-powered terminals and ducted fan coils use heated plenum air to offset perimeter loads.

Both fan terminals and fan coils require some energy to run the fans, so the use of fan-powered units is not without some penalties. In mild climates, the tradeoff between the equipment's first cost and operating cost may suggest that a single duct reheat unit is the most economical choice. The use of electronically commutated motors (ECM) can significantly reduce fan energy consumption in both fan-powered VAV and fan coils. Varying the airflow rate to the minimum required can make both fan terminals and fan coils very efficient, compared to constant volume non-ECM applications.

The *ASHRAE Handbook—Fundamentals* states that discharging air at a temperature greater than 15°F (27°C) above the room (90°F [32°C] in a 75°F [24°C] room) will likely result in significant unwanted air temperature stratification, likely exceeding the ASHRAE comfort standard's (55-2013 is the latest) vertical temperature stratification limits. Furthermore, ASHRAE Standard 62.1 (ventilation) requires increased outside air when heating from the ceiling if this rule is not followed (Standard 62.1-2013).

This is because hot air tends to stay at the ceiling and may "short-circuit" directly back to the room exhaust without mixing in the room. Indeed, using the ASHRAE Standard 129 test procedure for air change effectiveness measured mixing effectiveness values as low as 20% (or lower) have been observed in laboratory tests when the supply to room differential exceeds 15°F (27°C). Calculations will show that in most cases, 85°F (29°C) air will handle a typical winter design perimeter load at 1 cfm/ft^2 (5 L/s·m^2) air supply rate (the airflow rate likely required for both good ventilation mixing and comfort).

The maximum design discharge temperature should be no more than 120°F (48°C). This is the limit for electric heater units as set by the National Electrical Code. Insulation adhesives are also typically designed around this expected air temperature. If fan-powered units

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have a water coil located on the plenum inlet, caution must be used to not overheat the downstream fan motor. To be safe, the coil discharge temperatures should be limited to no more than 110°F (43°C). Engineers should take special care to ensure that both occupied heating and morning warm-up situations are covered in the design with proper stages of electric heat or proportional water coil valves.

The need to rapidly warm a space following a night setback has its own set of requirements. Air needs to be heated as rapidly as possible, with a maximum of mixing, without too much regard for occupant comfort. While this requires both a high ΔT and a high airflow, the physics of room air movement dictate that the hotter the air temperature, the longer it will take to heat the room for a given heat delivery rate due to stratification.

On the surface, reheating cold primary air seems to be a wasteful practice in terms of optimum utilization of energy resources; however, there are many situations where it is not only necessary, but also beneficial to do so.

Providing Comfort with a Great Diversity of Loads. When heating and cooling are required from a single air-distribution system due to climate and building design factors, reheat is often an economical solution. Considering it is used in a few locations only part of the time, the energy penalty for reheat is minimal.

Supplementing Baseboard Perimeter Heat. Baseboard heating systems can be the most effective means by which to offset perimeter heating demand loads. At times, however, peak heating demand loads may exceed the installed baseboard capacity and may require supplemental overhead heating.

Maintaining Minimum Ventilation Rates. The benefit of an installed reheat coil in a non-perimeter zone becomes apparent when the minimum ventilation rate exceeds cooling demand. This happens when the quantity of supply air to a space required to provide proper ventilation exceeds the quantity required to offset local heat sources, such as when the ratio of occupants to equipment (which requires little ventilation air) shifts toward occupants, as in conference rooms. As was observed in the recent ASHRAE research study RP-1515, modern computers and flat panel monitors give off such small amounts of heat that it resulted in interior systems going into reheat at minimum VAV settings. The system then maintained a heating setpoint several degrees below the normal interior temperatures, as required

FIGURE 1 Standard 62.1 rule on overhead heating.

Ceiling supply of warm air, at least 9 °C (15 °F) above space temperature, and ceiling return. **Note**: For cooler air, E_z = 1.0.	0.8
Ceiling supply of warm air, less than 9 °C (15 °F) above space temperature, and ceiling return ~~if~~ provided that the 0.8 m/s (150 fpm) supply air jet reaches to within 1.4 m (4.5 ft) of floor level. **Note**: For lower velocity supply air, E_z = 0.8.	1.0

by California code. Occupant complaints were frequent until VAV box minimums were lowered.

If ventilation minimums exceed the load or humidity control requires a higher airflow, a slight amount of controlled reheat can prevent subcooling. It is important that the room setpoint be maintained at the cooling setpoint, which for interior zones should be all the time. The alternative is to reduce supply air temperature at the air handler. This may result in other spaces that cannot be cooled at design maximum airflows and may increase the space's relative humidity.

Controlling Humidity. Both humidity and ventilation can be better controlled using reheat coils. When the local humidity is too high, drier, cooler air can be added, then slightly reheated to avoid subcooling. Fan coils may require both heating and cooling coils to be operated at the same time to control space temperatures and avoid sub-cooling. They also have to supply ventilation air. For this, a dedicated outdoor air system (DOAS) can be used to assist fan coils in dehumidifying as well as ventilating a space. In the case of fan powered VAV terminals, a sensible cooling coil on the induction inlet can offer increased flexibility and countless control options when coordinated with the ventilation supply unit.

Water Coil Selection

Most manufacturers provide software to accurately predict the performance of their products. In today's environments, it is common to see lower heating inlet water temperatures as well as higher water temperatures in sensible cooling coil applications. It is recommended that coil schedules be prepared using a program that has inlet and installation effects dialed in, as meeting the required Btu/h and gpm in a specification is often impossible if mounting condition factors are not used in the calculations. Unlike many air handlers, fin spacing, circuiting, and tube spacing are fixed for most VAV fan box and fan coil water coils.

With low loads being the norm, rather than the exception, minimum "capacity" is becoming a common problem. When water flow becomes too slow in a coil tube, it may become "laminar" and will make heat or cool difficult to control. This does not mean it will not transfer heat or cool, but rather we are unable to predict by how much! Proportional water valves in conjunction with modern thermostats work well to control space temperatures, adjusting water flow to meet demand, even when flow may become non-turbulent.

With non-condensing (sensible) cooling water coils appearing on both fan terminals and chilled ceiling induction units ("beams"), it is important that water coil entering temperatures stay above the local dew point to avoid condensation. Some building codes were recently modified to allow installation without a drain pan or to allow a catch pan on sensible coils, rather than a drain pan. It is always a good idea to place a condensation sensor on the inlet of a few sensible coils to alarm or close water valves if the water temperature falls below ambient dew points.

Common Water Coil Issues

Mixed Air Temperature. Mixed air temperature or unit leaving air temperature (the combination of primary and induced air temperatures) is dependent on the location of the coil. It is calculated differently for series or parallel fan powered VAV units:

Series Fan Units. For series fan units, heating coils are typically located on the discharge, where coil entering air temperatures are based on the minimum primary and the induced airflow. The induced airflow is the fan cfm less the minimum primary. With series flow units, the heating coil leaving air temperature and the box leaving air are the same. If a sensible cooling coil is used on the induction inlet, it must be included in the calculation of leaving air from the unit. If an ECM motor is provided, both coils, VAV (outside air) and induced air, may be varied by the on-board processor to allow for a wide range of operating conditions.

Locating the heating coil on the induction inlet is a possibility with an ECM fan motor, as it is able to deliver the same amount of air when the unit is essentially pressurized from the VAV inlet or when air is drawn through the heating coil. Preliminary data suggests that an ECM motor uses 40% more energy pushing (or pulling) air through a multiple row coil, compared to delivering 100% primary air with no downstream (or with an electric heating coil downstream). With lowered water temperatures requiring three- and four-row coils, this could be a significant energy saving strategy.

Parallel Fan Units. Most parallel units have the water coil on the discharge (despite the obvious pressure penalty seen by the primary air handler); while some designs allow locating them on the plenum inlet. This latter location makes the coil entering air temperature the same as the plenum air temperature. A parallel fan powered unit's discharge air temperature is a mix of primary air, typically at the minimum primary air flow rate, and plenum air at the fan airflow rate. This is the entering air temperature for a downstream coil. If the coil is on the induction port inlet, it is recommended that the heating coil leaving air temperature always stay below the maximum recommended for the motor, which is in the airstream.

Leaving Water Temperature. Air handler cooling coils are often selected on the basis of water coil ΔT. This technique, however, is not recommended for heating coils in VAV boxes or fan coils, non-condensing boilers require a high entering water (return water) temperature to avoid "shocking" the system. Ensuring a high return water temperature is best achieved through three-way valves, secondary loops or other means, not through coil selections. At part load, when the water valve is throttled, coil leaving water temperatures will *always* be less than recommended by these boilers.

Fluid Type. Three hot fluids are commonly used in coil applications: water, ethylene and propylene glycol. The use of glycol will significantly increase the minimum gpm required for turbulent flow and also reduces the specific heat of the fluid. Most programs compute a Reynolds number to determine the amount of turbulence in the fluid in the tubes, which is usually desired to be greater than 5,000. As the percentage of glycol increases, so too will the minimum gpm. Ethylene glycol is falling out of favor for environmental reasons, and propylene has a greater effect on minimum flow than ethylene.

Coil Load vs. Room Load. A water coil is often selected based on a given Btu/h. There are two loads that can be used for this calculation. One is the coil load, which is based on the airflow rate and the supply to discharge temperature differential. The other is the room load, which is the difference between the room and the unit

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discharge temperature; calculated by skin losses less internal loads. Often, it is not clear which is specified. Most programs assume the Btu/h load is the coil load.

Electric Heat Selection

The electric heater provided on most single duct VAV units is essentially a rated duct heater that is installed in an elongated single duct unit. This longer unit provides for a developed airflow after the damper and a relatively uniform airflow across the coil elements. Fan terminals and fan coils with electric heat typically place the heater on the discharge of the unit. The heater has a safety switch that prevents the heater from engaging, unless there is a minimum sensed velocity pressure in the duct. While this is normally a velocity pressure sensor, in practice, it sometimes acts as a static pressure sensor. At low flows, there may be insufficient velocity or static pressure in the unit to "make" the contactor in the flow switch. This may be due to probe location, damper position, low discharge static pressure or likely, a combination of all.

Meeting ASHRAE Standard 62.1's Ventilation Rate Procedure requires control of discharge temperatures to avoid the required increases in ventilation rates when heating from overhead. Proportional electric heat controls can provide this using either SCR devices or (quiet) solid state relays and time-proportional control, especially with a discharge temperature sensor as a part of the control logic.

With fan boxes and fan coils with electric heat, especially ECM motor driven units, the fan's minimum flow rate may not be sufficient to permit electric heat operation, so there may be a minimum setting based on cfm/kW and ΔT. The allowable kW is a function of unit size, voltage, and phase of the electric power supplied. With 480 V three-phase installations, a four-wire (three power leads plus a neutral lead) is usually required for power hook-up for fan terminals. Fractional hp three-phase motors are typically not available, and most fan box designs connect one leg of the 480 V three-phase to neutral to get a 277 VAC power tap for the motor. This means a 480 V three-wire connection (no neutral) to a fan box will require a very large transformer for the motor or a dual power connection. Some non-fan electric heat units are available with three-wire 480 connections, but minimum kW's may be limited. Again at low flows there is both a minimum flow and a maximum kW consideration.

Summary

When selecting electric, hot, or cold water coils, it is important that all selection criteria be considered; not only to ensure proper unit performance, but to also properly distribute heated/cooled air into the space. Amongst those considerations, one needs to also assure that discharge temperatures and air quantities offer both a comfortable space and provide for ventilation mixing. This is supported by ASHRAE Standard 62.1 (ventilation) and Standard 55 (comfort), which require proper selection of heating control, heating equipment, and air delivery devices. We cannot lose sight of Standard 90.1 (and Title 24 in California) either, as many items outlined in this and other mentioned Standards are required by most codes and are a prerequisite of the current LEED requirements. It may be necessary for the equipment supplier and control contractor to discuss these issues with the design engineer before making a final selection to ensure that everyone is making the same assumptions. ■