VAV TERMINAL UNIT SELECTION: USING REHEAT TO SAVE MONEY

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INTRODUCTION

VAV terminals provide a measured quantity of conditioned air to a space, in response to a control signal from a thermostat or room sensor. This air may be tempered with a reheat coil, plenum air, or both. The means and selection of parameters for this reheat leads to much of the complexity and questions in selecting and specifying VAV terminals. Selection of the reheat design parameters requires both an understanding of the limitations of the reheat coil (hot water or electric) and the means of air distribution, if problems in the installation are to be avoided.

OVERVIEW

Reheat is provided to terminal units primarily to allow for individual room controlled heat to perimeter zones. With fan terminals, this concept uses heated plenum air, supplied through ceiling diffusers, to offset skin load heating demands. Single duct terminals, however, normally reheat cooled primary air to offset perimeter heating requirements. This may be wasteful of energy, especially when the same air handler is using chilled air for interior zones which require year round cooling. Fan terminals require some energy to run the fans, however, so the use of fan powered units is not without some penalties. In mild climates, the trade-off between equipment first costs and operating costs may lead to the selection of single duct reheat units as the most economical solution.

The ASHRAE Fundamentals Handbook (now Chapter 20) states that discharging air at a temperature more than 15°F above the room (90°F in a 75°F room) will likely result in significant unwanted air temperature stratification. In addition, ASHRAE Standard 62.1 (Indoor Air Quality) has been modified to require increased outside air when heating from the ceiling if this rule is not followed (Standard 62.1 2010):

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

Figure 1

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 129 test procedure for Air Change Effectiveness, mixing effectiveness values as low as 20% (or lower) have been observed, when the supply to room differential exceeds 15°F. Calculations will show that in most cases, it only requires 85°F air to handle a typical winter design perimeter load at 1 cfm/SqFt. air supply rate (the airflow rate we recommend for both good ventilation mixing and comfort).

The need to rapidly warm a space following a night setback has another set of requirements. Air needs to be heated as rapidly as possible, with a maximum of mixing, without too much regard for occupant comfort. This requires both a high delta-t and a high airflow.
Note: *The hotter the air temperature, the longer it will take to heat the room, for a given heat delivery rate!*

This is due to stratification of hot air at the ceiling. The maximum design discharge temperature is probably 120°F. This is the limit for electric heater units, set by the National Electric Code. In addition, insulation adhesives are typically designed around this expected air temperature. If fan powered units have a plenum inlet located water coil, caution must be used to not overheat the downstream fan motor, limiting coil discharge temperatures to less than 110°F. The engineer therefore needs to ensure that both occupied heating and morning warm-up situations are covered in his design with proper stages of electric heat or proportional water coil valves.

The reheating of cold primary air seems, on the surface, to be a wasteful practice in terms of optimum utilization of energy resources. There are many situations, however, where it is not only necessary, but also beneficial to do so, and can save considerable energy. These include:

<u>Providing Comfort with a Great Diversity of Loads</u>: When both heating and cooling is required from a single air handler, due to climate and building design factors, reheat is often an economical solution. As it is only used in a few locations, and only part of the time, the energy penalty for reheat is minimal.

<u>Supplementing Baseboard Perimeter Heat</u>: Baseboard heating systems can be the most effective means of offsetting perimeter heating demand loads. At times, however, peak heating demand loads may exceed the installed baseboard capacity and supplemental overhead heat can be supplied.

<u>Maintaining Minimum Ventilation Rates</u>: The benefit of an installed re-heat coil in non-perimeter zones becomes apparent when a minimum ventilation rate exceeds the cooling demand. This happens when the quantity of supply air to a space required to provide proper ventilation exceeds that required to offset local heat sources, such as when the ratio of occupants to equipment (which requires little ventilation air) shifts towards occupants, as in conference rooms. In these cases, the required quantity of ventilation air may sub-cool the zone.

A slight amount of controlled reheat can prevent this sub cooling. The alternative, reducing supply air temperature at the air handler, may result in other spaces that cannot be cooled at design maximum airflows, and also tends to increases space relative humidity.

<u>Controlling Humidity</u>: Humidity control can be enhanced using reheat coils, just as for ventilation requirements. When the local humidity is too high, then drier cooler air can be added, and then slightly reheated to avoid sub cooling.

HOT WATER HEAT

The Krueger selection program (The Krueger KSelect VAV terminal selection program) is very powerful tools, with many options, but cannot defy the basic laws of physics, (regardless of what is specified). Unlike custom air handlers, the fin spacing, circuiting, and tube spacing are fixed for VAV box coils. This means that there is only one solution for a given gpm, # of rows and airflow rate, for a given coil size.

When selecting a coil, one can pick only one independent variable, with different parameters for increasing the number of rows, gpm, etc. There are 6 different calculation paths included in the program. The selection of the best path almost always requires a discussion with the engineer. If given a schedule to meet that is based on a coil other than Krueger's it is necessary to know which item on the provided schedule is to be met. While this should probably be the BTUH, it is often the gpm (which is apparently set in concrete due to prior pump selection), etc. Both scheduled gpm and BTUH cannot be met, unless the Krueger coil is the basis of design. Pick one!

As discussed earlier, the coil leaving air should be fixed so as to not exceed ASHRAE's recommended 15^{o}F delta-t maximum (Chapter 20, Fundamentals Handbook) except in unoccupied morning warm-up, for effective air distribution in the room (this is the default calculation method, method #2). This often requires adjusting the heating CFM to achieve the desired room BTUH at a discharge air temperature that will promote good room air distribution and ventilation mixing. This action is seldom performed, but should be. The user inputs the room temperature and the room load (not coil load), and the program calculates the necessary airflow at the selected leaving air temperature. With today's DDC controls, or with a parallel fan terminal, this reheat airflow setting is easy to establish.

WATER COIL ISSUES

Mixed Air Temperature: Mixed air temperature (the combination of primary and induced air temperatures) is dependent on the coil location. The KSelect program calculates the entering air temperature for water coils. It also uses a calculation to determine unit leaving air temperature on parallel boxes with a plenum inlet located coil (See below).

Series Fan boxes: As the coil is always on the discharge, the mixed air quantity (and the coil entering air temperature) is based on the fan cfm. The coil entering air temperature is calculated based on the minimum primary at one temperature and the induced airflow (which is the fan cfm less the minimum primary) at another temperature. With series flow units, the coil leaving air temperature and the box leaving air are the same.

Parallel fan boxes: With some parallel fan powered units, the coil location may be on the plenum inlet so the coil entering air is always the plenum air temperature. There is mixing after the coil, however. The units discharge air temperature is therefore a mix of primary air, typically at the minimum primary air flow rate, and plenum air heated by the coil, at the fan air flow rate.

Most parallel units have the water coil on the discharge, in spite of the obvious pressure penalty seen by the primary air handler. When on the plenum inlet, with a high minimum primary air setting (to meet ventilation minimums) the required coil leaving temperature may exceed 120F, and there is a high likelihood of ‘cooking’ the fan motor, forcing the coil to be relocated to the unit discharge.

Leaving Water Temperature: A method has been provided (#5) for solving for leaving water temperature. This was included primarily for a design evaluation tool, and should NOT be used in selection. Cooling coils are often selected on the basis of water coil delta-t, where the discharge temperature is controlled. This technique, however, is not recommended for heating coils in VAV boxes, where the discharge temperature is never controlled. It is recognized that non condensing boilers require a high entering water (return water) temperature to avoid ‘shocking’ the system. This should be accomplished 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: Water, Ethylene and Propylene Glycol. The use of Glycol will significantly increase the minimum gpm allowed for turbulent flow. Most programs compute a Reynolds number, which must be greater than 5000 for a valid selection, and which increases the minimum gpm as the percentage of glycol increases. KSelect allows for a Glycol calculation (Ethylene only).

Coil Load vs. Room Load: A water coil is often selected based on a given BTUH. There are, however, two loads that can be used for this calculation. One is the coil load, which is based on the air flow rate and the supply to discharge temperature differential. The other is the room load, which is the difference between the room temperature and the discharge temperature, and may be calculated from skin losses less internal loads. Often, it is not clear which is being specified. Most software assumes the BTUH load is the coil load.

ELECTRIC HEAT

The electric heater provided with Krueger LMHS series (Single Duct) VAV box is essentially a rated duct heater installed in an elongated single duct unit. This longer unit provides for developed flow, after the damper, and a relatively uniform airflow across the coil elements. At low flows, however, there is both a minimum flow and a maximum kW consideration. The heater has a safety switch that prevents the heater from engaging unless there is a minimum sensed pressure in the duct. Normally, this is a velocity pressure, although in practice, it sometimes becomes 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. (Note: for fan powered terminals, the minimum fan setting is sufficient to operate the electric heat).

LMHS Units

inlet size	Max. Primary Airflow - CFM	Min Airflow, CFM		Minimum Pressures		
		Standard*	Electric Heat**	Basic	EH	ΔPv
4	229	40	55	0.23	0.47	0.43
5	358	62	85	0.20	0.41	0.42
6	515	89	110	0.17	0.33	0.41
7	701	121	140	0.16	0.32	0.40
8	916	159	190	0.17	0.34	0.39
9	1159	201	240	0.17	0.33	0.38
10	1431	248	300	0.17	0.34	0.35
12	2060	357	425	0.17	0.33	0.33
14	2804	486	580	0.18	0.36	0.29
16	3662	634	750	0.17	0.34	0.24
24 x 16	7000	1212	1800	0.18	0.35	0.29

* This value is based on a signal of 0.03 in w.g. of the linlet probe. Minimum may be 0.
** A minimum 0.03 discharge static pressure is required to set the flow switch

Figure 2

The table here lists the minimum flows currently required for electric heat with Krueger LMHS Single Duct units. We recommend a minimum of 0.03 inWg. external (downstream) pressure to assure that the safety switch sees enough pressure to activate the heater. The kW selected at minimum flow must also avoid exceeding the maximum UL listed coil temperature of 120F.

Besides the minimum flow to activate the heater safety circuits, there is an issue of the diffuser performance. All diffusers have a specific performance envelope. With VAV systems, diffusers should be selected so that at full flow they are near the limit of objectionable sound, so as to allow for optimum performance at reduced flows. VAV boxes are also selected at as high an inlet velocity as possible, for the same reason. When heated air is being discharged from a ceiling diffuser, the outlet velocity needs to be as high as possible, to prevent stratification. Airflows even close to the electric heating minimum shown in the above table are unlikely to be satisfactory from an air distribution standpoint, and short circuiting of ventilation air and excessive temperature stratification are likely, regardless of the resultant discharge temperature.

Some Energy codes (currently in Florida and California), and ASHRAE 90.1, prohibit reheating cooled air at more than 30% of design cooling flows. It is unlikely that meeting this requirement will result in satisfactory diffuser mixing, occupant comfort or ventilation mixing. In temperate climates, this may be a less than satisfactory, but an understood design compromise. In cold climates, this may not be acceptable. There is a caveat in the 90.1 standard allowing for higher reheat quantities to meet Ventilation or IAQ requirements.(See section 6.3.2 of ASHRAE Standard 90.1). A new addendum to 90.1 allows up to 50% of cooling flow maximum, if the unit controls discharge temperature and starts at 20% sing VAV heating airflow.

In some cases, it may be desirable to decouple the heating and cooling air supply to the room. One option is to use down blow nozzles at the window supplied from a heating only fan coil. A parallel fanbox controller on the single duct VAV terminal used for cooling can control this fan coil.

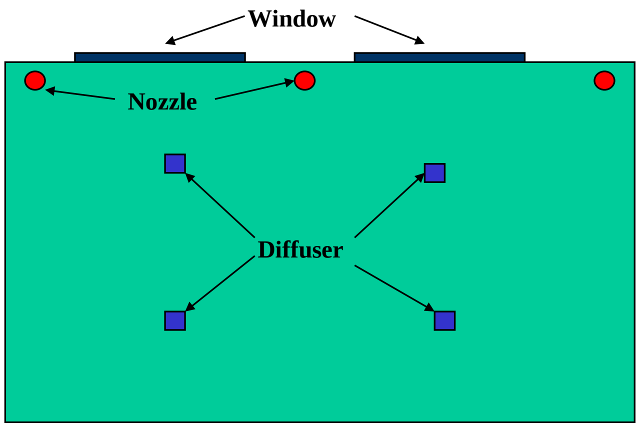

Figure 3

Further, ASHRAE Standard 62.1 (now 2010) now requires an increase in ventilation rates when heating from overhead, to counter the likely ventilation short circuit that is likely at high turn down rates, unless discharge temperatures are limited to 90^{o}F, or less, and the 150fpm throw makes it to within 4.5ft of the floor.

With fan boxes, the fan's minimum flow rate is sufficient to permit electric heater operation, so there is no minimum setting or requirement. Additionally, as there is minimum reheat, energy codes are satisfied, and diffuser performance is maintained. As a result, when restrictive energy codes are in place, fan powered terminals may be required for acceptable environments and ventilation mixing. See the table on the previous page for VAV damper minimum flows as a function of control type and inlet size.

As mentioned earlier, the ASHRAE Handbook recommends (and ASHRAE Standard 62.1 requires) a maximum discharge temperature of 90^{o}F (in a 75^{o}F room) with overhead heating to avoid excessive stratification (and ventilation short-circuiting), except in morning warm-up (Fundamentals, Chapter 33). Many times, simple logic can be applied to select suitable conditions of airflow and reheat which maintain room air mixing, diffuser performance and air change effectiveness, within the factory airflow and kW limitations for units with electric heaters. We recommend 1cfm/sqft as a heating flow rate in perimeter zones to achieve optimum air distribution when heating.

ELECTRIC HEAT WIRING ISSUES

The allowable kW is a function of unit size, voltage and phase of the electric power supplied. Notice that with 480 three-phase installations; only 4-wire (three power leads plus a neutral lead) is available for power hook-up, as a standard option. No manufacturer makes a fractional HP 3-phase motor, so a fan box unit must connect one leg of the 480 3-phase to neutral to get a 277 VAC power tap for the motor. A 480V three-wire connection (no neutral) to a fan box, therefore, requires a very large transformer for the motor. With single ducts, the lead times are increased because the unit is a special order. (Note: none of this is easily accomplished in the field!)

The allowable kW is not infinite, but must be selected from the table built into the K-Select electronic catalog selection program (and shown in the price pages). The K-Select program only allows selections of valid kW's. The K-Select electric heat selection screen will calculate selection parameters based on the last input variable entered before the 'Calculate' button is pressed. Selecting stages of heat is also important. If large capacity heaters are required, as many stages as possible (3 maximum!) should be selected to avoid temperature set-point overshoot. Note that some control sequences have only 2 stages available.

HEAT CONTROL

The control of heat to a space is primarily the responsibility of the supplied DDC controls; the exception being pneumatic and analog electronic. The controller provides staged contacts for heat to an electric heater, and either a single contact for on-off, or two contacts for three point floating outputs to a hot water valve. The control is most often open loop, in that the controller relies on feedback from the room sensor to modify the heater control signal. If a room is stratified (as when the discharge air temperature is greater than ASHRAE's recommended 15°F delta-t, the time response may be very slow, resulting in considerable room temperature swings (in addition to the stratification).

A new proportional discharge temperature controlled heat option is now available with Krueger VAV terminals, with both electric and hot water heat. This is a patented electronic time proportional controller (trade named LineaHeat). The controller is connected either to a PWM equipped proportional hot water valve, or a single stage digital relay version of the electric heater, and is available with an optional discharge temperature sensor. This sensor allows the controller to set the desired discharge temperatures as a function of the DDC controller's demand. The LineaHeat option allows for a better control of space temperature than other methods. It can be driven by a variety of application sequences using proportional (0-10 VDC or 0-20 mA) output, pulsing or staged 24 VAC output. The (patent pending) three-point floating input option – with either hot water or electric heat – often reduces the cost of the DDC controller by as much as $100 compared to a proportional output on the DDC controller. With most DDC controllers, adding an analog output is either a different and more expensive controller, or requires an add-on module. Either option typically adds $100 to the controller cost, more if the second module has to be separately mounted and wired. Some DDC manufacturers do not have an analog output option available at all.

When the discharge temperature sensor is installed, the unit controls proportionally between the no-heat duct temperature and the set maximum temperature. Without a sensor, the unit proportions the amount of supplied heat between 0 and 100% of the supplied kW or allowable GPM range. These sequences are factory set but can easily be field modified to match available controls and needs.

With hot water valves, the use of an actuated flow compensated ball valve can further enhance the performance and control of heat to a space. A compensated ball valve results in linear heat delivery as a function of the ball position. If a further control is added to regulate the water pressure at the valve, proportional heat results independent of water pressure fluctuations.

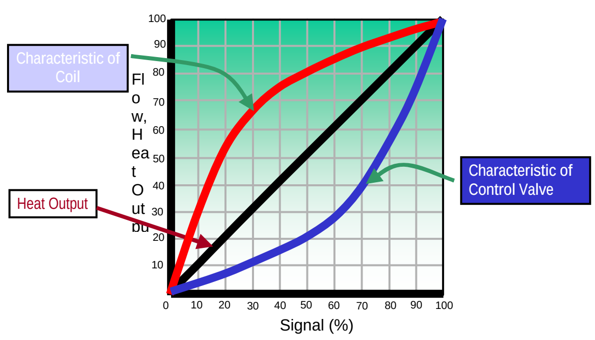

Figure 4

SUMMARY

Electric and hot water reheat coils are provided on many types of VAV terminals. There are selection criteria for each that should be considered both to ensure proper unit performance and to distribute the heated air properly into the space. With all, however, the engineer should assure that the discharge temperatures and air quantities will provide a comfortable space, and provide ventilation mixing as well. It will often 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

Meeting both ASHRAE Standard 62.1 and Standard 55 requires proper selection of both heating control and heating equipment, as well as air delivery devices. At the same time Standard 90.1 (and Title24 in California) must be followed. As meeting 62.1 is a prerequisite of the current LEED requirements, it is essential that these issues be understood by all parties.