LINEAHEAT:
DIGITAL HEATER CONTROL

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OVERVIEW

Krueger has introduced a new option for all its VAV terminals – proportional discharge temperature controlled heat. Trade named LineaHeat, this patented low cost option will allow true proportional electric and hot water heat control at a very affordable cost, and will enable solutions to a number of problems associated with overhead heating applications.

Why Proportional Heat Control?

In order to provide comfort, indoor air quality through proper ventilation, and energy savings, the discharge temperature and the air flow rate of a VAV zone controller must both be managed. Hot air will stratify at the ceiling if the discharge temperature is too high, and the velocity too low. Worse, ventilation air will return to the ceiling located return opening without mixing in the room.

On a cold day, cold air will fall down a cold window, regardless of the heating strategy. The hot air from the ceiling diffuser works best when the primary jet reaches this cold downdraft, mixes with it, and tempers the cold air stream to a comfortable temperature.

ASHRAE Standard 62.1 2010 requires a 25% increase in the ventilation rate if the discharge temperature is too high (>15^{o}Fabove room temperature) or the velocity too low (150 fpm terminal velocity must reach ½ way down an external wall).

In many cases, staged electric heat and most hot water control systems cannot provide the necessary flexibility to meet the above requirements. With improved perimeter glass and insulation, the heating demands are often low, and energy codes are many times proscriptive in terms of reheat flow rates.

The LineaHeat controller solves all three needs. It optimizes the combination of flow and reheat, allows for the maintenance of velocity and temperature control, and most importantly, can be used with all DDC controllers currently offered on the market today.

The LineaHeat product employs a non-communicating digital electric heat controller to send a pulse modulated output to the solid state relay in a provided electric heating circuit. The LineaHeat module is an easily configured circuit board that can be factory set or field modified to accept inputs of 0-10 VDC, 0-20 mA, or 24 VAC from the DDC controller. Other applications include direct pulsing and intermittent staging from the DDC controller. Unique is the Three-Point Floating application that allows low cost controllers to proportionately modulate heat with 2, 24 VAC outputs. An optional discharge temperature sensor causes the LineaHeat controller to maintain a desired discharge temperature based on the input signal, as a percentage of the board set maximum. (See #3 below)

Is It Cost Effective?

<u>Electric</u> - In the past, the cost-add for proportional electric heat has been on the order of $750-$1000/zone. This is because a third party heater must be specially built, shipped and installed on a VAV unit. The heater must be qualified for use with the specific VAV terminal that is a part of the overall cost. Finally, SCR electronic controls were much more expensive in the past, with high amperage elements requiring expensive heat sinks and special circuits. Advances in electronics now allows for much lower cost control components, and when the heater is built in-house, there are no coordination, shipping and handling issues, and the UL qualification is a part of the overall qualifications.

As low cost digital relays are now available, the best value will be realized with single-phase power, as three-phase circuits will require multiple digital relays. With improved exterior walls and glass, most applications should be able to utilize single-phase heat, once the economy of this choice is realized. The LineaHeat controller is available in either single or three phase versions. The control can be applied to

Single Duct as well as fan powered VAV units. The optimum first cost use is probably on Parallel fan powered units, if the proposed ASHRAE requirement is to be met.

SCR vs. DIGITAL RELAY CONTROL – ELECTRIC HEAT

The traditional method of providing proportional electric heat has been the use of a silicon controlled rectifier, or SCR. Basically, the SCR chops the 60 cycle wave form so that the full sine wave is not delivered to the heater. Often employed so that the supply voltage is “chopped” as the current passes through zero volts (“zero crossing”), the SCR reduces the current to the heater 60 times a second. In some cases, this 60 cycle pulsing results in feedback on the power line, and at low loads, the heater element never gets very hot, which can have some corrosion potentials.

In the past, mercury contactors have been employed as an alternative to SCR control, as they are very quiet. Mercury is now often regulated by local environmental regulations, and sometimes prohibited. In addition, the in-rush of current drops the 24 Volt transformer voltages, which sometimes causes problems with the digital controller.

When using a relay, the current to the heater is interrupted at much longer intervals, typically on the order of one second or so (depending on the duty cycle required). The heater gets hot enough to remove contaminants and dust, and the potential for feedback on the power lines is minimized. The solid-state relays used in the LineaHeat system are silent, and have no current in-rush, so they do not affect the digital controls, and have little feedback on the power line. In addition, the solid-state relays run cool enough that the electric heater cabinet is not louvered, as with some competitive models, so a dust tight enclosure is possible.

UNDERSTANDING REHEAT ISSUES

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 and the means of air distribution, if problems in the installation are to be avoided.

Reheat is provided to terminal VAV units primarily to allow for perimeter zone temperature control separate from adjacent interior zones. Warm air is supplied through ceiling diffusers to offset skin load heating demands. With fan terminals, both warm plenum air and supplementary heat, and a minimum of primary air (to meet ventilation demand) is provided. Single duct terminals, however, reheat only primary air to offset perimeter-heating requirements, which may be a wasteful use of energy, especially when the same air handler is using chilled air for interior zones that require year round cooling. In winter, when it is colder outside, economizer systems avoid cooling primary air, saving energy.

Fan terminals require some energy to run the fans, however, so the use of fan-powered units is not without some penalties when in full cooling (summer) mode. 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. In addition, we are seeing an increased use of low wattage reheat single duct units in interior zones to avoid sub cooling while meeting minimum ventilation rates set by local codes.

Since 1980 the ASHRAE Fundamentals Handbook chapter on Air Distribution (now Chapter 20) has stated that discharging air at a temperature more than 15°F above the room (for example 90°F in a 75°F room) will likely result in significant unwanted air temperature stratification. In addition, ASHRAE Standard 62.1 2007 (Indoor Air Quality), has been modified to require increased outside air when heating from the ceiling (Table 6.2, excerpt shown below):

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/Sq.Ft. 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 apparently has another set of requirements: air needs to be heated as rapidly as possible, with maximum mixing, without too much regard for occupant comfort. There is a tendency to use this as the design load requirement. In practice, this requires both a high delta-t and a high airflow to get both temperature rise and air mixing.

Note: *The hotter the air temperature, the longer it will take to heat the room, for a given heat delivery rate! Therefore excessive heating delta-t may actually make the morning warm-up cycle take longer*

The problem is stratification of hot air at the ceiling. The maximum possible design discharge temperature is 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. 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.

Providing Comfort with a Great Diversity of Loads: 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.

Supplementing Baseboard Perimeter Heat: 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.

Maintaining Minimum Ventilation Rates: The benefit of an installed re-heat coil in non-perimeter zones becomes apparent when minimum ventilation rates exceed 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.

Controlling Humidity with Sub Cooling: 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.

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 attenuated 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.

The table below lists the minimum flows currently required for electric heat with Krueger LMHS Single Duct units. We recommend a minimum of 0.03 in. Wg. 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 NFPA specified maximum coil temperature of 120^{o}F.

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.

LMHS Units

	Max. Primary	Min Airflow, CFM		Minimum Pressures		
inlet size	Airflow - CFM	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

Some Energy codes (currently in Florida and California) and ASHRAE 90.1, prevent 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 understood, compromise design. In cold climates, this may not be acceptable, but many systems will be in economized mode, thus avoiding the airflow limitation. 90.1 has an addendum (BX) that allows up to 50% of cooling airflow if starting at 20% with VAV heating and controlled discharge temperatures. Further, ASHRAE Standard 62.1 now requires an increase (25%) in ventilation rates when heating from overhead, to counter the likely ventilation short circuit that is likely at high turn down rates, if discharge temperatures exceed the ASHRAE Handbook recommended 15°F Delta-t, and if diffuser throws are too short.

With fan boxes, the fan's minimum flow rate (provided there is a little discharge pressure) 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 above table for VAV damper minimum flows as a function of control type and inlet size.

With the LineaHeat control, Krueger can manage all the requirements listed above, regardless of the type of zone controller installed, and works for both Electric and hot water coils. The Krueger LineaHeat comes with an optional leaving air temperature (LAT) Sensor. This sensor is capable of being mounted up to 6 feet from the heater discharge for accurate temperature measurement of ducted air. The sensor in connection with the heater control board comes with an adjustable marked pot to dial in the desired maximum air temperature. Controlling the discharge temperature to a percentage of the set maximum value (probably 90°F with a 75°F room set point) meets ASHRAE 62.1's requirement as well as assuring occupant comfort (and meeting ASHRAE Standard 55 2010). Without the sensor, heat is provided proportional to demand. When the sensor is installed, the LineaHeat controller proportions the amount of heat between the no heat condition and the desired maximum set point. A properly configured zone controller can increase the airflow if heating demand loads are not being met. The following outline several features and benefits to be realized in utilizing the LineaHeat control.

Three Point Floating Input: The LineaHeat module can be controlled through two primary paths. It can respond to a variable input signal, such as a 0-10VDC or a 4-20mA current control. Unfortunately, this often increases the cost of the DDC zone controller by a third or more, or requires an add-on option for analog controls, when compared to a simple (and lower cost) digital output controller. Another (patented) input option on the LineaHeat controller allows for connection to the two 24VAC digital outputs normally used for a "three point floating" hot water valve. These digital contacts are usually programmed to increase or decrease the water flow through a "floating, modulating" hot water valve. With the LineaHeat control, one output provides a gradual increase of the desired heat output. The other output can slowly decrease the desired heat output. This allows proportional heat changes to the point that either the LAT sensor set point or room thermostat is satisfied. The result is proportional electric heat at a significantly lower installed cost than with other "SCR electric heat" designs requiring the proportional output from the controller.

Optimization of Overhead Electric Heating: Overhead heating has been in common use since the mid '70's. With electric heat, three stages of heat are typically selected to provide variable heat output to the perimeter zone. As glass R and U values have improved, the required heat capacity has decreased. Typical 'rules of thumb" should probably be re-evaluated with these new building components. Our analysis indicates that at an airflow rate of 1 cfm/sq.ft., it takes less than 10°F Delta-t to maintain comfort in an occupied space. Typical installed heating capacities, based on units ordered over the past couple of years, are observed to be capable of two to three times this capacity. As a result, many systems are operating with essentially one stage of reheat, and provide poor comfort in the space as the discharge air fluctuates from heating to ventilation, or worse, heating to cooling temperatures.

By using proportional electric heat, a single heat element can be utilized with greatly increased control, and attendant occupant satisfaction. This allows greater flexibility to the designer, and allows for future interior load variations as well. If tied to the optional discharge temperature-limiting sensor, compliance to ASHRAE standard 62 is assured. If coordinated with the control supplier, heating airflows can be increased if demand is not satisfied, and the heater controller will automatically adapt to the higher airflows. This maintains minimum reheat with single duct reheat systems, and optimizes selection of fan-powered units. It also allows for different settings in morning warm-up mode.

Cost of DDC Controller (0-10vdc vs. Three Point) - A DDC or Analog Zone controller can provide outputs for installed unit reheat. With electric heat, this is typically accomplished with three stages of low voltage contacts, or triac, connections. For an additional cost, typically on the order of $100, a DDC controller can provide a proportional output, usually a 0-10 VDC signal. This can be used to control an SCR electric heater or a proportional hot water valve. In the past, specialty heater suppliers, at a cost of several hundred dollars, have manufactured SCR electric heaters. These special heaters must be UL certified to work in conjunction with a close coupled VAV valve or fan. Long lead times and coordination issues add to cost and complexity. DDC control suppliers cannot provide this control because of the requirements for in-line testing as a part of the heater, which typically they don't provide.

By providing a factory built digitally controlled electric heater, normal lead times and low costs are maintained. UL certification is provided as a part of the assembly. The assembly is independent of the DDC or analog control supplier, which are all low voltage components.

Quiet and Environmentally Friendly Operation: The magnetic contactors typically provided with multiple stage electric heaters make a clicking noise when they are engaged. It is for this reason that mercury contactors are sometimes specified. While nearly silent in operation, mercury contactors can add significantly to the cost of a heater, and may cause problems with digital controller power supplies. Recent environmental concerns, however, have made the use of mercury contactors less of an option. Some local codes require registration of such devices, and careful controlled disposal.

Digital relays, however, are both silent and environmentally friendly. New electronic technologies coupled with lower perimeter loads have resulted in better heat dissipation and lower costs, making this application both affordable and practical.

Improved Control for Low Heat Demand: When used in interior zones to avoid sub cooling, LineaHeat electronic heat control really shines. Very low kW settings, or oversized water coils and valves, coupled with higher minimum airflow ventilation rates, often create conflicting requirements. Proportional reheat can assure excellent comfort and ventilation mixing in the space at all load conditions.

In temperate climates, where the low heating loads result in low kW and gpm requirements, it is often impossible to provide three stages of heat or one row hot water is too much, resulting in poor temperature control. Proportional heat allows for better temperature control in mild climates.

ASHRAE has recently approved a requirement for Demand Controlled Ventilation in all large single zone applications under ASHRAE Standard 90.1 (Energy). If a DDC controller coupled with a CO2 sensor is properly configured, proportional reheat can help meet this requirement. A local zone's airflow rate can be increased to meet a sensed ventilation requirement, without requiring the entire system's outdoor airflow rate be adjusted upward.

Standard 90.1 also issued an addendum to the standard, Addendum BX, which allows up to 50% of cooling airflow in heating if discharge temperatures are controlled, and VAV heating starts at 20% of cooling rate. This means that a VAV box can now be used for reheat at airflows that will allow the diffuser to still mix air in a room. Standard 55 must still be complied with in most locations, and that means a discharge temperature less than 90°F is still a requirement to keep vertical stratification within the allowed 5°F vertical in the occupied zone. LineaHeat provides an obvious cost-effective means to make both of these requirements work.

SUMMARY

With changes in standards, the need for better control of overhead heat is imperative. Krueger's new LineaHeat option provides cost effective temperature control that will allow designers to meet the new ventilation requirements, while assuring low first cost and maximizing occupant comfort.