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Differential Temperature Control in Hydronic Heating Systems

Abstract: With the advent of condensing boilers, variable speed drives, and modern control platforms engineers and sys-tem designers are now in a position as never before to review and rethink the control concepts of hydronic heating systems; to go beyond the higher combustion efficiencies of the condensing boiler and take complete advantage of a more dynamic system control concepts leading to even greater energy savings for their clients.

Change of Vision: The Introduction of Outdoor Temperature Reset

Over time the hydronic industry has changed the approach to system piping designs and temperature control as equipment efficiency and technology has evolved. In the late 1960's and early 1970's hydronic system introduced outdoor air reset. This allowed for better temperature control in the occupied space at a significant reduction in energy cost with reduced water temperature. This thought process of reducing water temperature as the outdoor air temperature increased caused the control valves operating the space temperature to stay open longer. This also revealed proof that the terminal units were still sized large enough to satisfy the conditions at lower water temperatures. The only unfortunate reality was the standard boiler design only allowed minimum return water temperatures of 140° F to prevent them from condensing the flue gases. Most boiler designs utilized steel and cast iron as the choice in heat transfer media until copper was introduced and perfected in the early 1980's. The modular copper boiler design resolved the thermal shock issues, but 140° F was still the lowest acceptable return water temperature. With the introduction of modulating firing rate and as water mass boilers were being replaced with the new evolution in the modular boiler design, the flood gates opened to new technologies and opportunities.

New Controls Put Energy Conservation within Reach

TAs new controls technology (in the late 1990's) became very affordable with introduction of electronics, the entire industry changed once again and new standards were invoked in the hydronic industry that revolutionized energy conservation. Energy would now be considered a performance based opportunity rather than just a cost of doing business. With the ability to monitor the entire buildings from a central point and to optimize energy efficiency with very precise controllability, we created a new series of problems with the boiler technology and system designs of the past. The requirement to operate at return water temperatures well below the 140° F as a norm presented real challenges to the boiler industry.

Condensing Boilers are Introduced

As energy costs continued to rise and all the recent demands from the controls industry, the boiler market traveled down a very unique path adaptability until the late 1990's

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when the condensing boiler was first introduced. In the past boilers were protected by three way valves as well as unique piping configurations and pumping techniques all attempting to adapt the modular boilers to existing systems, maintain reset temperature capability as well as protect the heating device from condensing, but when presented improperly these techniques would ultimately shorten the equipment life by short cycling or corrosion from low water temperatures which became inherent to the misapplied designs and operating conditions.

Fixed Temperature Systems Challenged

In most systems designed over the past 50 years in the hydronic industry the temperature differential across the supply and return was approximately 20° F with operating temperatures of 180° to 160° F. This was the basis for all pipe sizing, pump selections, and terminal unit approach temperatures. This was a very safe design and a steadfast rule until the recent development in condensing boilers and central point controls technology. It has only been recently that control valve positions and system flow rates have been easy to monitor and control. This monitoring presented a wealth of information which surprised the industry and allowed many to capitalize on future designs. If we look at the actual system temperature differential of the standard 20° F design we are able to show that this differential temperature actually only occurs less than 0.5% of the total system operation time. When a system is designed for the maximum heat loss and flow rates across the system are-fixed, the 20° F applies to design day conditions only while the balance of the operating hours the system differential in something less than 20° F.

VFD Technology Employed

The system terminal units are traditionally under utilized and water circulation is typically more than the system requires providing the required output during operations other than design day conditions. This was the beginning of industry standards which utilize VSD (Variable Speed Drive) or VFD (Variable Frequency Drive) for most circulation pumps in the hydronic systems.

The Problem with Delta P Control Strategy

The system supply provides a desired water temperature at a specific flow to the system while the control valves react to the space conditions and open or close. Think about the control valves and terminal units for a moment: A control valve is reacting to the space conditions. If the valve closes the space is satisfied, this would be an indication that the water temperature is to hot. If the water temperature was too cold then the valve would stay open because there would not be enough heat to satisfy the space. Sounds reasonable? The terminal units do not know nor do they care what the differential temperature is across the unit; it is the control valve that does all the work. If the terminal unit has more flow than it needs during operation it just passes through the additional flow and temperature to the return line.

As the control valves close the pressure differential across the system will increase because the same volume of water is attempting to flow through less piping. By monitoring the pressure differential between the supply and return we can typically slow the pump down. However, it is only a reference as to how many valves are open vs closed because the system can have the same differential pressure at full load (winter) when the pump is running at full speed as it could at partial load (spring/fall) when the pump is running at partial speed with valves closed and higher water temperatures throughout the system. The differential pressure control has no way of knowing the supply temperature or the differential temperature across the system. There is no way to verify that the original 20° F differential temperatures designed into the system would actually occur, other than during the design day conditions. Example: as 50% of the valves close the pressure differential would automatically slow down the pumps but the assumed 20° F temperature difference across the system may not be present, unless it could be monitored.

The Advent of Delta T Control

What is the significance of monitoring the temperature differential you ask? We established that the water temperature causes the valves to close, why not lower the water temperature to control the space temperature and leave the valves open longer. If the valves stay open and the water temperature passing through the terminal units actually has a chance to dissipate the heat completely rather than pass it on to the return line we could effectively control the supply and return temperature across the system. System designs

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based on outdoor air reset coupled with temperature controlled variable flow rates, to create condensing opportunities, causes the system to maintain a balanced differential temperature between the supply and return. The position of the control valves and the pressure differential in the system would lend itself to the direct correlation between the temperature across the supply and return. Sending hotter water back to the heating device actually lowers the overall system efficiency. One must have the opportunity to use all the available heat in the terminal device and have the lowest possible return water temperature to take advantage of the high efficiency condensing capabilities in industry today. The control valves would close or modulate as the space conditions allow, changing the temperature in the return, slowing the pumps to maintain a desired temperature differential. Nothing in the typical system design changes but the return temperature is actually monitored and flow is controlled based on temperature differential across the system rather than the temperature differential being a result of the slower pumping and higher temperatures. The preferred method of temperature control is to tie together (parallel) the firing rate signal with the flow rate VFD signal based on a supply and return water temperature. A specified system differential temperature of approximately 30° F (adj.) when achievable is the preferred operation. The pressure differential control signal could be utilized as a minimum system set-point, if desired, to protect low end flow only.

Adding Outdoor Air Reset into the Mix

As an added feature to the system operation, outdoor air reset temperature requires a particular set-point; the boiler water set-point differential can be shifted or lowered by +/- 5° F which will allow the system control valves to stay in the open position longer. Working with a lower boiler discharge (supply) water temperature the building is scheduled at the lowest potential temperature. The individual unit control valves will not have to close prematurely due to excess water temperature in the system, similar to a boiler short cycling because it is oversized for the load. The control valves should act as a "high limit device" allowing the water temperature to control the space temperature utilizing the lowest possible water temperature available for that specific zone at all times. Several water temperatures set-points may be necessary to satisfy the load but always revert back to the lowest temperature when ever possible.

Night Set-Back and Boiler Sequencing

The building terminal units/loads should be energized from setback mode on a sequencing schedule. Each load should have a minimum time when energized to allow the boiler to catch the load before a second load is energized and set-point established. Night "Set-back" should be accomplished by reducing water temperature +/- 15° F (adj.) as a shift to a lower water temperature rather than terminal loads shut down completely. The building temperature will be reduced due to lower water temperature while not causing morning start-up inefficiencies due to higher than necessary boiler firing rates. This will allow the boilers to operate in a lower fire input matching the building heat loss at lower building temperatures. The staggering sequence to an occupied set-point will allow the boiler to operate at low fire input rather than high fire and utilize multiple boilers operating to match load, increasing the overall thermal operating efficiency. This method of sequencing the boilers to satisfy hot water return (HWR) temperature set-point should occur regardless of the system water flow rate.

Flow Meter Incorporation

If a flow meter is incorporated into the system design: "NOT REQUIRED" in the main system header piping then the boiler firing rate should be tied (parallel) to the pump flow rate signal. With temperature sensors on the supply and return of the system and the system flow through the flow meter is known, a simple system BTU's/Hr calculation can be made in real time as an attempt to maximize the boiler firing rate based on an actual BTU's required to satisfy the load.

Boiler Operation

Introducing a specific designated 20 minute time delay between boiler stages and a 20 minute ramping firing rate will give the boilers a chance to react to the system load before driving to high fire. A typical system designed with a 20° differential should have a circulation of at least once back to the boiler in less than 10 minutes. If we ramp the boiler firing rate over 20 minutes the system control valves should have ample time to react to the load and provide an average return line temperature. Using the return line for a set-point location offers a very stable place to sense the actual system load with very few radical changes.

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Many experts will challenge the analogy of total energy savings of shutting the system down at night vs reducing the temperature of the water and leaving the pumps operational. The energy consumed by the pumps running at a substantially reduced flow rate and horsepower would be less power than starting the system at a specific time in the morning warm-up at full capacity. The control valves will be wide open and the system temperature differential will cause the boilers to operate at a higher firing rate and temperatures to satisfy the load quickly.

What if: We could use a sensor in the living space with a similar function to that of the outdoor air sensor to override to the outdoor air sensor. If the space "**Temperature Requirement**" is satisfied the water temperature would not have to increase based strictly on outdoor air temperature alone. If the inside air temperature falls below a given desired temperature, only then would the water temperature be allowed to increase and the pump speed increased.
We could set up an individual indoor air reset curve for the conditioned space temperature changing the water temperature with respect to the outside air temperature. The two temperatures reset curves could work to compliment each other and attempt to keep the water temperature as low as possible at all times. Why raise the water temperature just because the outdoor air temperature curve plotted requires us too when this is the only reference point that has no input feedback from the actual space conditions. This simple concept could take the guesswork out of what water temperature is required to satisfy the space temperature.
The success to any of this thought process is to incorporate a learning period to examine how the building will react to the operating conditions and then customizing the operation. Constantly looking at water temperatures required to satisfy the conditions will be the key to energy savings. This is not a fix for every system design but an opportunity to think differently than we have for so many years. Run the system continuously at the lowest possible water temperature in your design. Typically systems are oversized and will have the capacity available if needed anyway.

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