Heat Exchanger Set Point Optimization Assignment

If you are using the electronic version of this document, you can quickly navigate through it by opening up the bookmarks feature for the .pdf version or the navigation pane for the Word version.

Issues and Opportunities

Many if the issues and opportunities we will encounter will have their roots in an issue associated with the original building or how it was adapted over time, including changes that were made that unintentionally crippled the original design intent behind some of the systems. Many times, these issues represent opportunities in an existing building commissioning process.

This exercise focuses on example of just such an opportunity in the context of the control of the control of the heating hot water supply temperature. Originally, as you may recall from the narrative describing the history of the building or my comments in class, the system had a reset schedule that adjusted the hot water supply temperature as a function of outdoor air temperature.

But that feature was lost during one of the renovation cycles when reheat coils were added, and the designer opted to maintain the design hot water temperature at all times to ensure the performance of the reheat coils. The designer retained the zone valves on the FTR system, allowing the limit control thermostats to modulate them, not fully appreciating how the performance of FTR varies with flow.

As a result of these changes, the building tends to over heat during mild weather, even though it is comfortable on cold days. And there is constant bickering between the staff regarding the appropriate setting for the FTR zone thermostats.

The good news is that if you restore the reset schedule and adjust the hot water supply temperature as a function of outdoor air temperature, you likely will alleviate some of these problems, especially if you educate the building occupants and operators regarding how the system is intended to work and about the features that are there to fine tune it to their needs, like the dampers on the FTR covers for instance.

In addition, you will also save some energy. And you can achieve these benefits by a very simple modification to the basic logic we developed, which is the point of the exercise.

Statement of the Problem

During the class session, we developed the basic logic for the heat exchanger serving the heating hot water system in the fictitious Department of Bureaucratic Affairs Building.

And we discussed how finned tube radiation (FTR) capacity is very much a function of the average water temperature seen by the elements and is not impacted significantly by flow variation. Thus, the hot water temperature control strategy currently in place at the facility (maintaining a constant supply water temperature and varying the flow to the elements to control zone temperature) is not a very good way to control the system and probably is causing comfort issues.

As a result, you could improve the comfort in the facility by replacing the fixed set point for the PI loop in the control logic with a variable set point that was adjusted by some sort of reset strategy. Specifically, you could reset the supply water temperature based on outdoor air temperature, thereby matching the available capacity from the FTR elements to the need for heat. In doing this, you will also save energy because you will reduce the parasitic losses from the piping network.

All of this can be accomplished by a relatively simple modification to the control logic, making it a very attractive EBCx opportunity. Your assignment is to modify the basic control logic we developed by replacing the fixed set point with a reset strategy.

The rest of this document provides you with the resources you need to accomplish that, including a cleaned up version of the basic logic for you to use as a starting point, and a review of the operating principles of finned tube radiation heating. I also provide an in depth discussion of the methodology used to develop the temperature settings we would apply for the reset schedule. We touched on the principles in class, but I "do the math" later on in this document.

Related Resources

Bureaucratic Affairs Building Model

This model is in an early stage of development, but it will give you a “visual” on what the piping for a Finned Tube Radiation (FTR) and reheat system looks like. The piping circuit is complete except for the pumps, warm-up coil, and heat exchanger in the mechanical room.

Bureaucratic Affairs Building Description and History

This document describes the history of the Bureaucratic Affairs Building from its construction through the multiple renovation cycles that have brought it to its current state.   In an Existing Building Commissioning process (EBCx) we frequently find ourselves involved with buildings that have a long and checkered past just like this one does.   Gaining knowledge into the past history of the building and it’s systems can often give you insight into a problem you are investigating or maybe even reveal the design intent behind a system you are working with.

Bureaucratic Affairs HW System Diagram

This is a PowerPoint file that illustrates the configuration of the heating hot water system that is served by the heat exchanger which is the focus of the exercise.

It includes a lot of important design information in terms of the installed capacities of equipment, design conditions, rated capacities, set points, etc. all of which will help to establish the requirements for the control process.

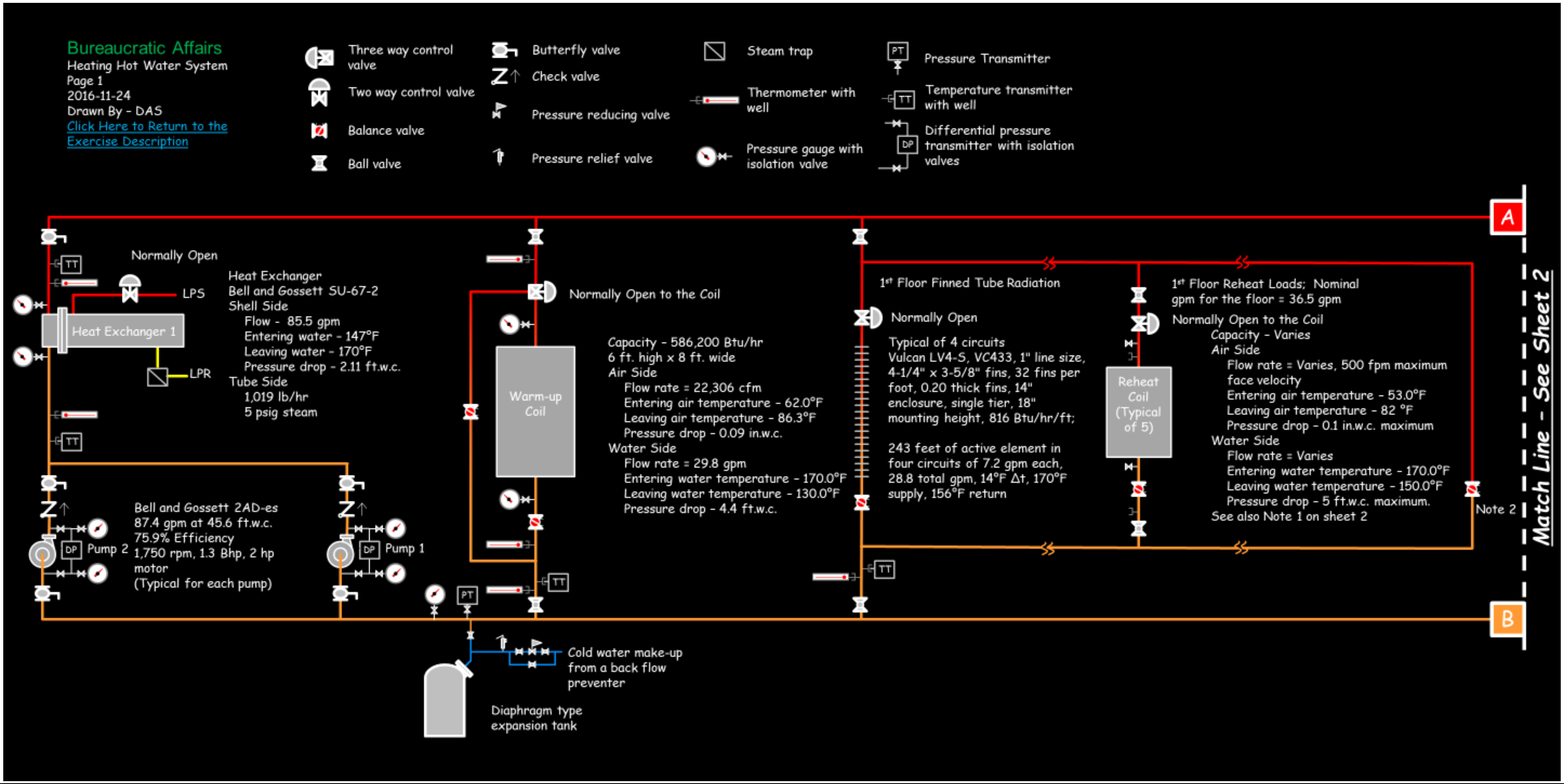

Figure 1 – Hot Water System Diagram – Page 1

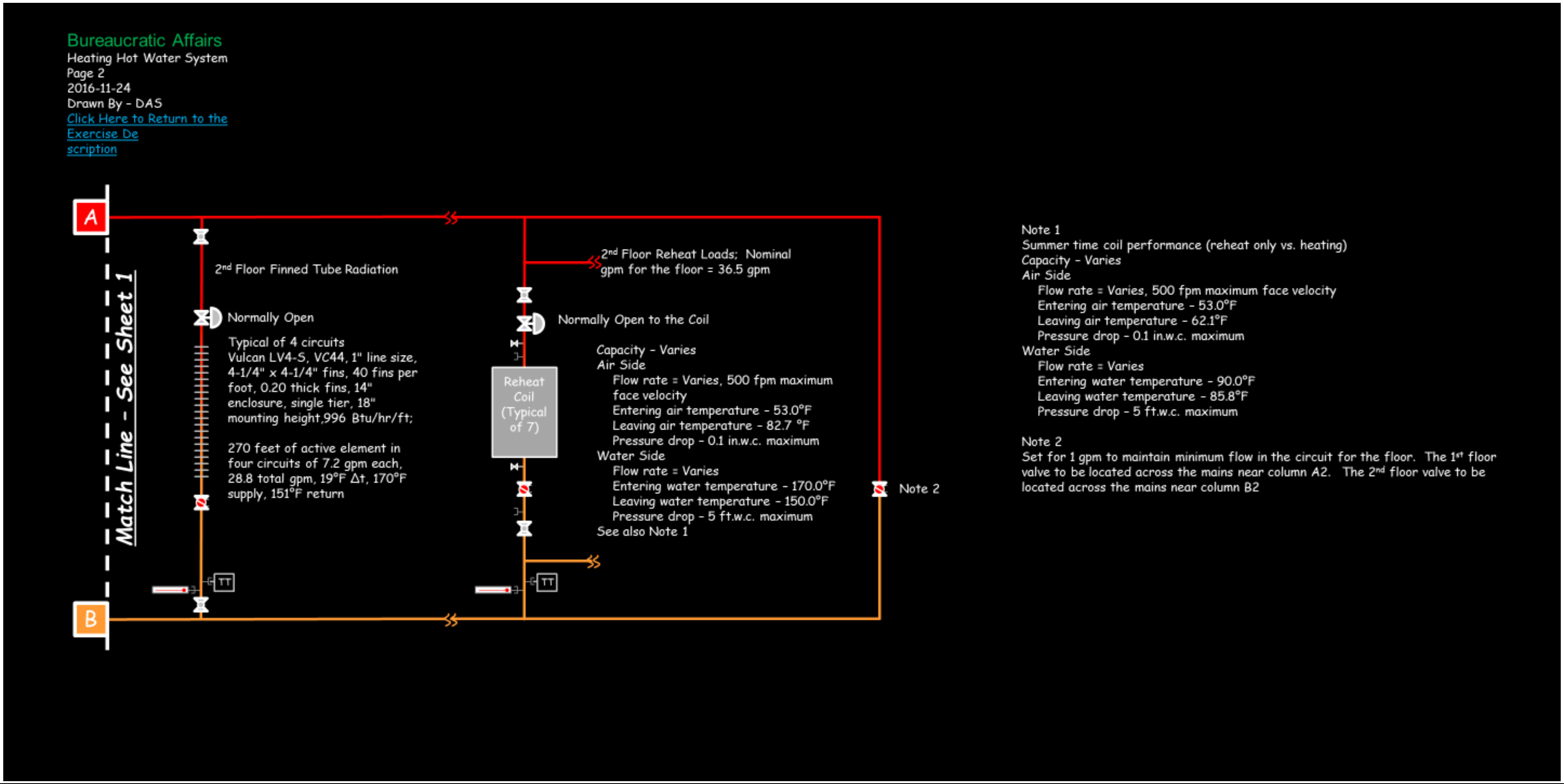

Figure 2 - Hot Water System Diagram – Page 2

Bear in mind that you can download a PowerPoint system diagram tool and associated symbols as well as all of my AutoCAD system diagram symbols and some sample system diagrams in AutoCAD and PowerPoint from this page on the FDE Cx Resources web site.

http://www.av8rdas.com/system-diagram-symbols.html

Bureaucratic Affairs Hx Basic Logic

This is a cleaned-up version of the logic diagram we built together in class to provide the basic control for the heat exchanger and is the starting point for your work of adding a reset schedule.

The spreadsheet version of the file was generated in the logic diagram tool and you can work with it that way by adding it as a tab in your copy of the tool or by copying and pasting symbols from the tool into a copy of the spreadsheet.

Remember, you can always download the current version of the logic diagram tool, the PowerPoint file that describes the symbols, and some examples of logic from the Logic Diagram Tool page of FDE's commissioning resources website.

http://www.av8rdas.com/logic-diagram-tool.html

The FDE Cx Resources website also has links to other logic tools along with examples for them which you can use to learn how to use logic, including running your logic in a simulation mode.

http://www.av8rdas.com/eikon-for-educators-and-windlgc.html

Finally, if you want some examples of logic diagrams, system diagrams, and control system specifications and standards, you can visit this page of the FDE Cx Resources website.

http://www.av8rdas.com/control-and-logic-diagram-standards.html

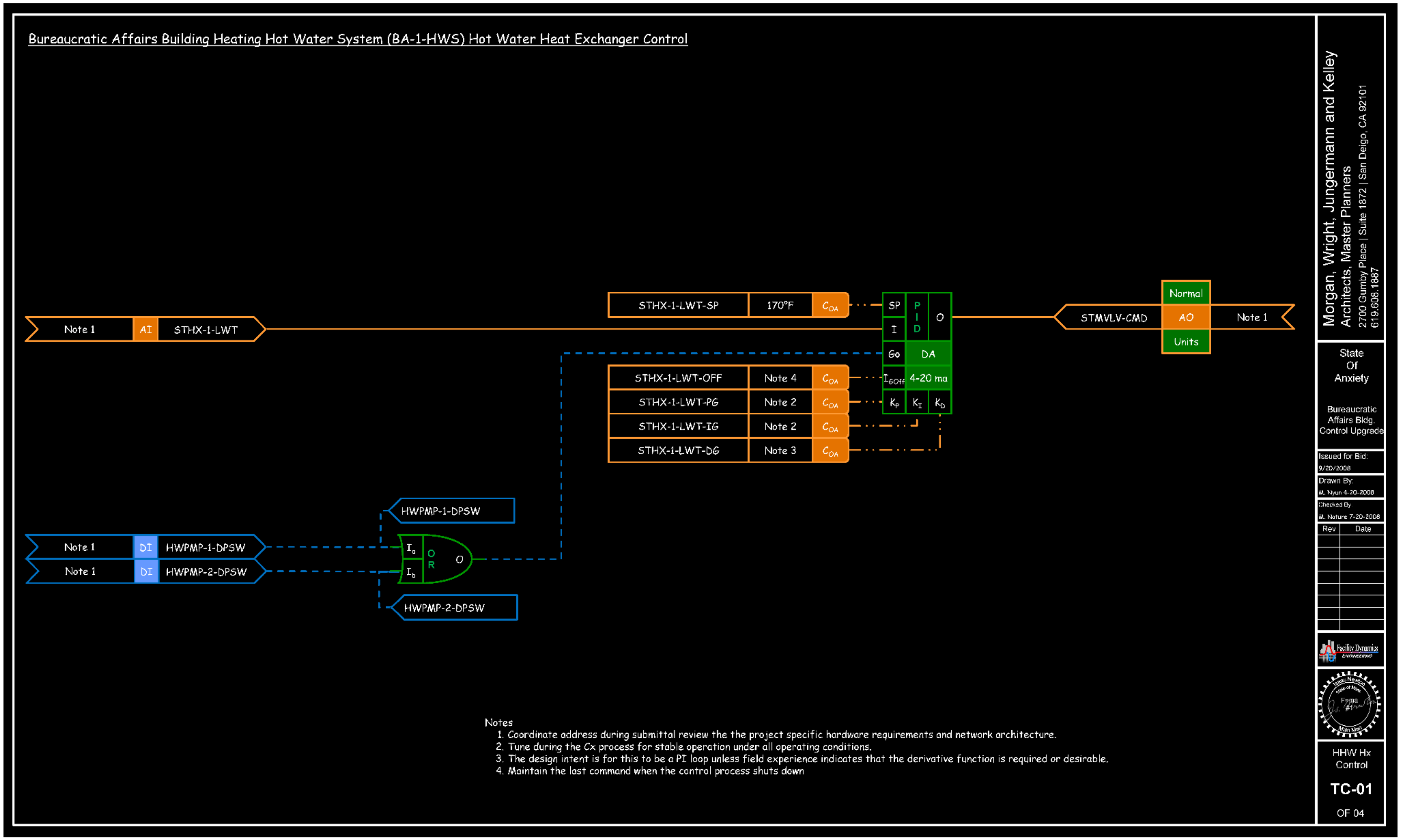

Figure 3 – Basic Heat Exchanger Logic

Bureaucratic Affairs Point List

This is the formal point list associated with the logic. In general terms, it is the control system procurement version of a monitoring plan. If you are buying controls, it is an important basis of design document and gives you a lot of control over the bidding process if you use it properly.

Frequently, I tell people if they do nothing else but a point list as a mechanism to procure their control system, they will have made great strides toward a better installation compared to just asking for a price and taking what you get. If you supplement that with a narrative sequence and a system diagram, you will be doing yourself and the project a great service in terms of leveling the procurement playing field and providing resources to support ongoing operations.

You should expand this point list to include any points you need to add to the system to do your reset schedule.

Bureacratic Affairs Building 1st Floor Hot Water System																
Point		Sensor			Features											Notes
Name (Note 6)	Description and Service	Type	Reference Spec Paragraph	Accuracy	Alarms				Trending							
					Limit		Warning		Samples[1]	Commissioning[5]			Operating[5]			
					Hi	Lo	Hi	Lo		Time[2]	Local[3]	Archive[4]	Time[2]	Local[3]	Archive[4]	
Analog Inputs																
STHX-1-LWT	Shell and Tube Heat Exchanger -1 Leaving Wtr. Temp.	1,000 Ω Pt RTD with close coupled transmitter and thermometer well	25 35 00	0.75% of span for sensor + transmitter	Note 7				60	1 min.	X	X	1 min.	X	X	Note 8
Analog Outputs (All analog outputs to include local override capability and status indication at the controller)																
STHX-1-STMVLV-CMD	Shell and Tube Heat Exchanger -1 Steam Valve Command	4-20 ma actuator	25 35 13	N/A	N/A	N/A	N/A	N/A	60	1 min.	X	X	1 min.	X	X	
Digital Inputs																
HWPMP-1-DPSW	Hot Water Pump -1 Differential Pressure Switch	Penn model P74FA-5 differential pressure switch	25 35 16 2.04	N/A	Note 7				10	COV	X	X	COV	X	X	
HWPMP-2-DPSW	Hot Water Pump -2 Differential Pressure Switch	Penn model P74FA-5 differential pressure switch	25 35 16 2.04	N/A	Note 7				10	COV	X	X	COV	X	X	
Virtual Points																
STHX-1-LWT-SP	Shell and Tube Heat Exchanger -1 Leaving Wtr. Temp. Set Point	N/A	25 35 00	N/A	Note 7				10	COV	X	X	COV	X	X	
STHX-1-LWT-PG	Shell and Tube Heat Exchanger -1 Leaving Wtr. Temp. Proportional Ga	N/A	25 35 00	N/A	Note 7				10	COV	X	X	COV	X	X	
STHX-1-LWT-IG	Shell and Tube Heat Exchanger -1 Leaving Wtr. Temp. Integral Gain	N/A	25 35 00	N/A	Note 7				10	COV	X	X	COV	X	X	
STHX-1-LWT-DG	Shell and Tube Heat Exchanger -1 Leaving Wtr. Temp. Derivative Gain	N/A	25 35 00	N/A	Note 7				10	COV	X	X	COV	X	X	
STHX-1-LWT-OFF	Shell and Tube Heat Exchanger -1 Leaving Wtr. Temp. Loop Off Value	N/A	25 35 00	N/A	Note 7				10	COV	X	X	COV	X	X	Note 9

Notes:

1. Samples indicates the minimum number of data samples that must be held in the local controller if it is trending the point.
2. Time indicates the required sampling time for the trending function.
3. A check in the local column indicates that the trending only needs to be running in the local controller and the most recent value can write over the last value when the trend buffer fills up.
4. A check in the archive column indicates that the trend data must be archived to the system hard disc when trend buffer fills up so that a continuous trend record is maintained.
5. Commissioning trending requirements only need to be implemented during the start-up and warranty year. After the start-up and warranty process, the control contractor should set the trending parameters to the operating requirements listed if they differ from the commissioning requirements.
6. Point numbers are based on the Owner's point naming convention which is included in the specification. Point names will be verified during the submittal process in the control system integration and coordination meeting.
7. To be determined during the Control System Integration and Coordination Meeting
8. Furnish two wells for installation adjacent to each other by the mechanical contractor. One well is for the sensor and one is for calibration purposes. See the spec and detail.
9. The design intent is that the control loop is a PI loop with derivative added only if tuning in the field indicates that it is necessary to manage the response to a step change or reduce the settling time. Coordinate with the control system designer and Owner proir to adding derviative gain, but provide the point so it is there if needed.

Figure 4 – Basic HX Control Point List

The point list is provided as a .pdf document but also in the form of the spreadsheet tool we (FDE) use to generate our point lists. The point list is actually a pretty good way to come up with a budget so the tool includes a budget generator based on the type of points you enter. Drop down menus let you pick point names from lists that can be tailored to the project specifics to keep things consistent.

Don't let it overwhelm you; you don't have to use it; I included a version that is just the list without all the "whistles and bells" as well as a .pdf version. But frequently, I am asked for a copy of the tool, so I am providing it as is for your use if you want to. It is totally editable and has an instructions tab that explains how it works. The top rows of the template page explain the general structure of point names and is based on a common convention.

If you choose to use it, bear in mind that it is a FDE internal working tool, and you need to assume responsibility for the results including the pricing factors and other information it contains. What works for us on our projects may not work for you on yours. And there could be bugs in there that we have yet to uncover.

Bureaucratic Affairs Building Basic Heat Exchanger Control Narrative Sequence

This is a narrative version of the logic. The narrative sequence and the logic complement each other. The narrative makes the logic more understandable for "normal" people. But, because of the specific definition associated with a symbol, developing the logic diagram as a way to communicate your intention can be more "bullet proof" than just writing a narrative.

I know of some fairly experienced control system designers – myself included – who are constantly discovering weak points in their best narratives when they convert them to a logic diagram.

As a result, for myself personally, the narrative and the logic diagram develop concurrently. Usually, I start with a bulleted list version of the narrative, which helps me get a start on the logic. But then I move into the logic diagram to work out the details. Once I finalize the logic, I go back and fill in the details in the narrative.

If you are looking for some guidance in all of this, the link below has articles that discuss the basic steps in developing a control sequence from different perspectives (you'll be able to tell the perspective from the title of the articles) along with some other articles about control system design.

http://www.av8rdas.com/magazine-articles.html#Controls

Typical Reheat Coil Selection

The file with the extension .ghcoil is a model of a typical reheat coil created using the Greenheck Coil Selection software. This is a free program you can download from the Greenheck web site.

http://www.greenheck.com/resources/software/coil-software-selection-program

The model allowed be to select a reheat coil for a design condition where it needed to provide heat (deliver air warmer than the space) and then see how it would perform with lower water temperatures when all it needed to do was reheat (deliver air to the space that was cooler than the space but warmer then the air handling system leaving air temperature).

As a result, I was able to come up with a point on the reset schedule for summer time operation, a condition where the finned tube radiation would no longer be in operation but reheat would be required for temperature and humidity control.

Bureaucratic Affairs Building Metrics

This is the spreadsheet file that has all the "math" behind the Bureaucratic Affairs Building model. It will provide an understanding the general layout of the facility and some of the design metrics behind the equipment since some of that information cannot be derived from the current model.

Bear I mind that the model is always evolving and as it evolves, some of the metrics may be adjusted to meet the needs of the exercises associated with the model. Usually I update the spreadsheet when I do this but if there is a conflict between what you see in the model or a system diagram and the spreadsheet, assume the model or system diagram is the most accurate information for equipment performance metrics.

PowerPoints Regarding Setting VAV System Supply Air Temperature and Minimum and Maximum Flow Rates

These are a set of PowerPoint slides that I use when I teach about VAV systems to explain how the minimum and maximum flow rates are determined. The reason they matter for this exercise is that once you understand the concept behind how these parameters are set in a VAV system, you then understand why we have to do reheat if we want to keep our buildings clean, safe, comfortable, and productive.

Since the hot water system in our exercise serves reheat loads, we need to be sure that if we reset the temperature down in warm weather, we still deliver water that is warm enough to serve the reheat loads that exist in the summer. That means you need to understand these concepts. These slide sets will provide some insight in that regard. Ultimately, I would like to do a blog post on the topic but have not gotten that accomplished yet, so I offer these in the interim.

Finned Tube Radiation Characteristics

Physical Appearance

To properly control something, you need to understand how it works, even something as simple as finned tube radiation. As you can see from the model, finned tube radiation (FTR) is pretty much what the name implies; a section of pipe with fins mounted on it (Figure 5).

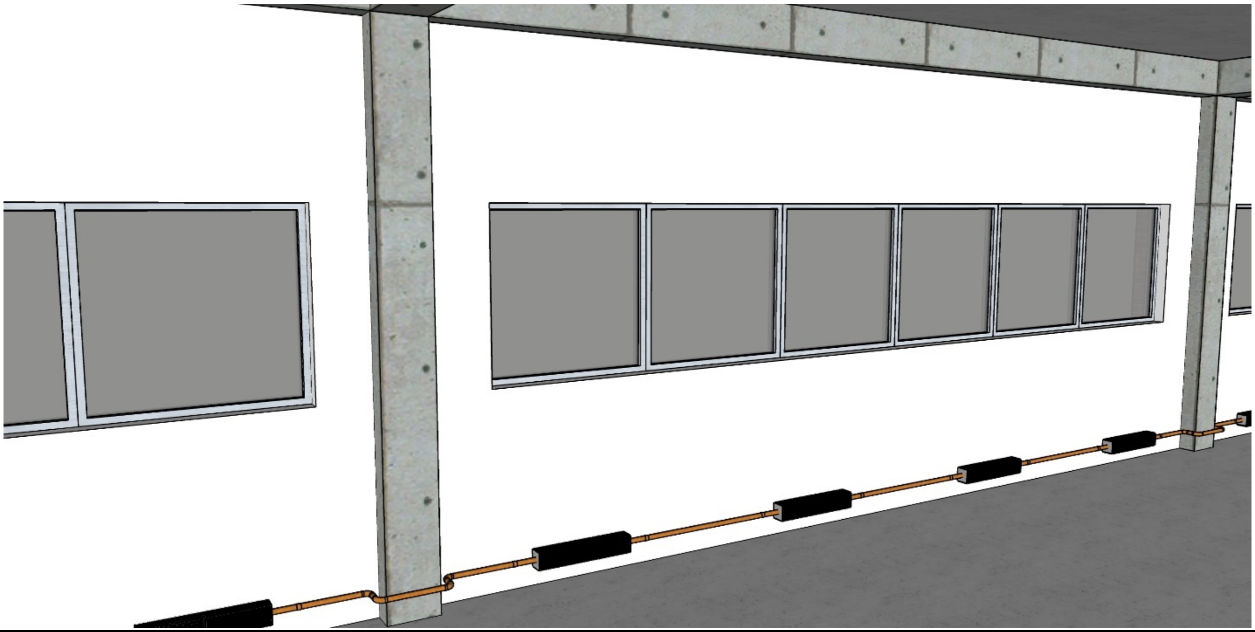

Figure 5 - Typical FTR Elements Along the Perimeter

Figure 6 illustrates what a typical enclosure might look like.

Figure 6 – Typical FTR Enclosure

Note the optional damper that is visible in the cross-section and allows the occupant to adjust how much convection occurs.

The system is intended to function as a perimeter heating system with the idea being that you put the source of heat adjacent to the location where the loss in heat is occurring from, thereby offsetting the load at the point where it occurs.

Performance Characteristics

The amount of heat transfer that occurs is nearly linear with the supply water temperature for a given element design, as can be seen from Figure 7.

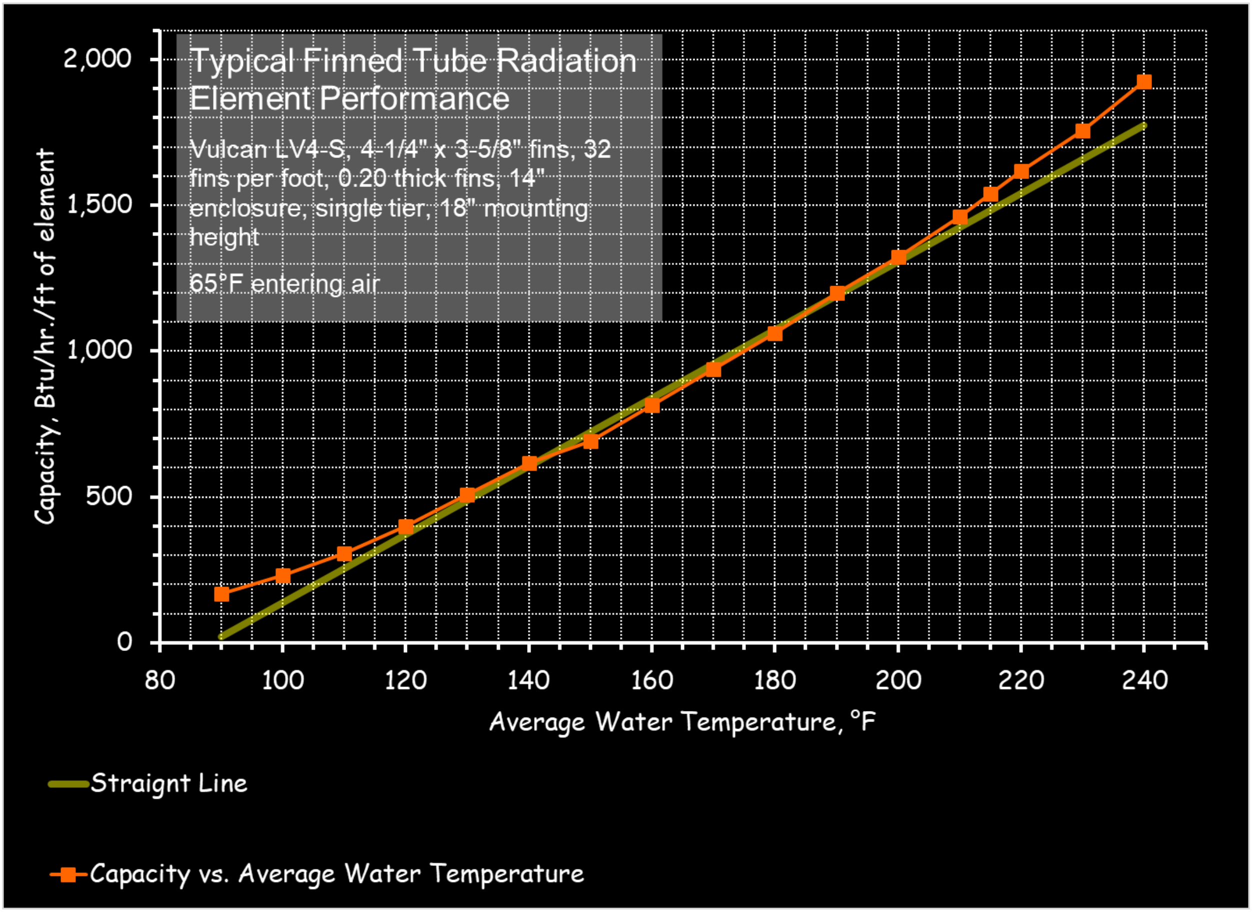

Figure 7 - FTR Capacity vs. Water Temperature Contrasted with a Straight Line

This makes FTR fairly attractive as a means for offsetting perimeter heating loads because for a given wall construction, the amount of heat required to maintain steady state conditions inside a building will vary linearly with the temperature difference across the wall as can be seen from Equation 1.

$$Q = U \times A \times \left(t_{Inside} - t_{Outside}\right)$$

Where:

$Q =$ Heat transfer in Btu/hr
$U =$ Heat transfer coefficient in Btu/hr - square foot - °F
$A =$ Area in square feet
$\left(t_{Inside} - t_{Outside}\right) =$ Inside to outside temperature difference in °F

Equation 1 – Heat Transfer Through a Wall

The system is also a very comfortable heating system because the heat is placed between the occupant and the source of the energy loss, bathing the wall with warm air and leveraging the effect of radiation heat transfer. If you have ever warmed yourself in front of a fire, you have experienced this. You can be a significant distance from the fire, but if you are in the line of site, you feel the warmth due to radiant heat transfer. The closer you get, the warmer you will feel because the amount of radiant energy transferred varies with the distance.

Part of the heat transfer process that occurs with FTR is due to the convection that is set up inside the enclosure when the element locally warms the air, causing it to rise and flow out the vents at the top, with the flow being regulated by the damper. When the warm air leaves the enclosure, cooler, denser air flows in from the bottom to replace it.

But convection is only part of how the heat transfer occurs. Radiation heat transfer also plays a roll because the metal enclosure and the wall and air in the immediate vicinity of the element is warm and thus transfers heat by radiation, even if the damper is fully closed.

That means that while the damper will allow the occupant to fine tune the capacity of the element, an additional mechanism is required to allow total control of the capacity of the FTR elements. One approach that seems logical is to vary the flow, which is the approach the designer of the 1985 renovation took to allow the reheat coil supply temperature to remain constant at the design point.

But if you explore how FTR capacity varies with flow, you will find that it is not what you might have expected, as can be seen from Figure 8.

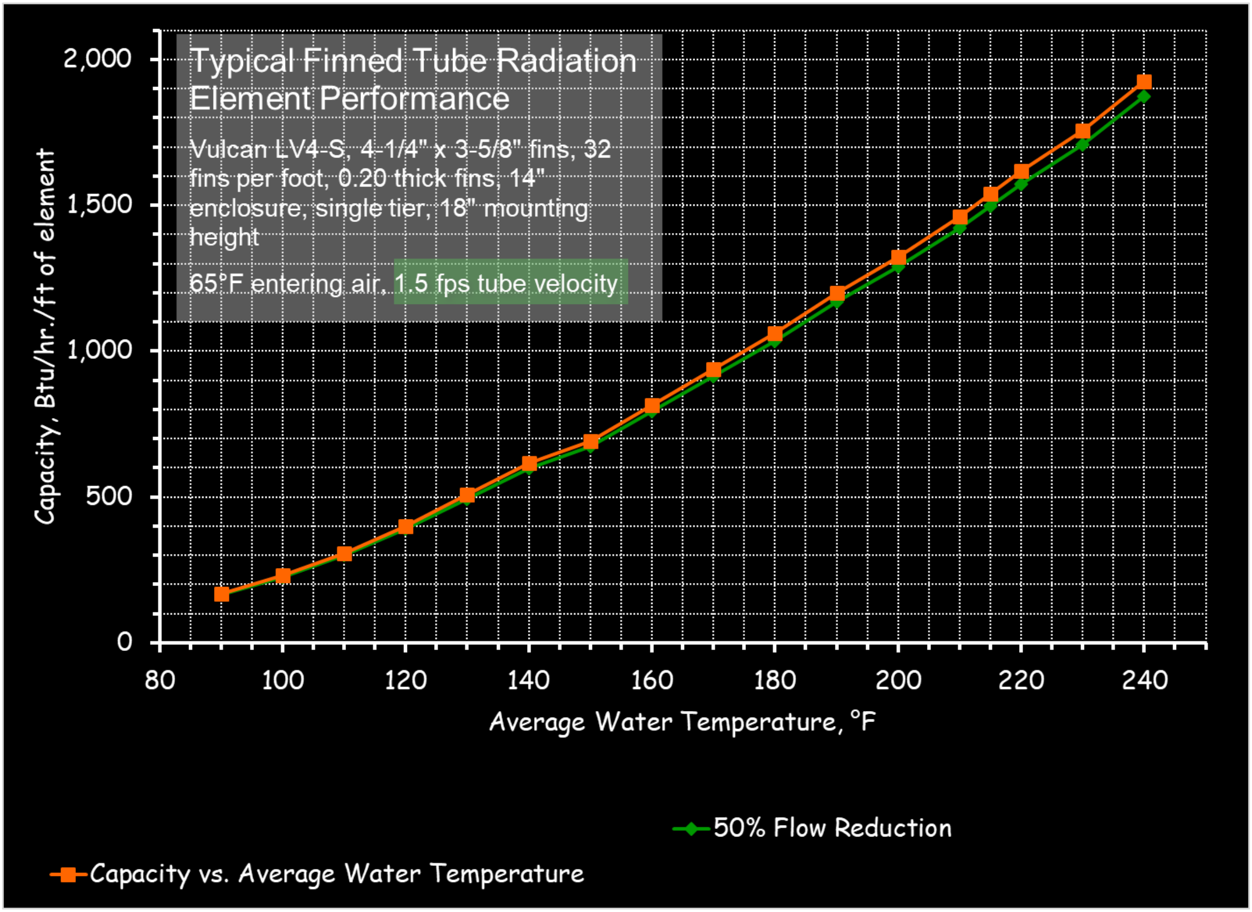

Figure 8 – FTR Capacity Change Associated with a 50% Reduction in Water Flow Rate

Flow Variation vs. Water Temperature Variation for Capacity Control

If you study Figure 7 and Figure 8 for a while, you will likely conclude that varying the water temperature to the FTR elements will be a much more effective way to control them vs. varying the flow. That was the reasoning behind the reset schedule that was used by the original design, which adjusted the FTR supply water temperature based on outdoor air temperature.

At this point, you can probably also see why the facility might be comfortable in cold weather but tend to overheat in mild weather. In cold weather, design or near design capacity will be required from the finned tube element; i.e. the capacity delivered by supplying it with the design hot water temperature. But as it warms up outside, maintaining the design supply temperature provides significantly more capacity than is needed and attempting to control it by modulating the line size zone control valve is not a very effective way to reduce the capacity, partly because of how FTR works (Figure 8) and partly because a line size valve will not have a very good control characteristic in terms of being able to modulate flow.

The Role of a Properly Sized Control Valve

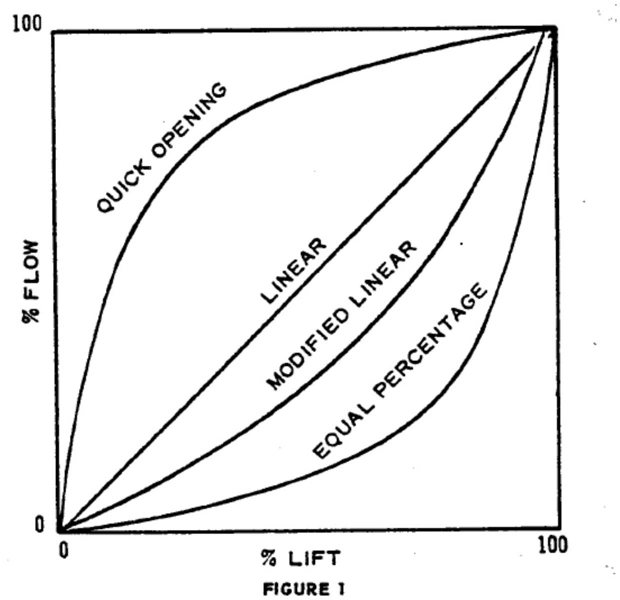

Figure 9 - Typical Control Valve Characteristics

Figure 9 is taken from the MCC Powers *Application Engineering Form AE-1 – Powers Control Valve Selection and Sizing*[1] and illustrates the flow vs. valve plug travel characteristics for a number of different valve types. A line size valve will tend to have a *Quick Opening* characteristic, which, as you can see produces a very non-linear response.

Consider the following scenario. On a cold, near design conditions morning, the FTR control valve would be wide open because there would be a significant need for heat to offset losses through the envelope. But, as it warmed up outside, the demand would be reduced which would cause the zone thermostat to start to close the valve to try to reduce capacity.

But as you can see, by following the *Quick Opening* curve from the right (100% open position) to the left, the valve would need to move through most of its stroke to reduce the flow by 50%. And as you can see from Figure 8, a 50% reduction in flow would not have much impact on the capacity. As a result only a very small portion of the over-all valve modulating range would be effective at providing a meaningful change in FTR capacity, making it difficult for the valve to find the exact, right position to balance capacity with load. In practical terms, it would be like trying to fill a tea cup with a fire hose.

In the original design, the valves were only intended to function as "On-Off" control mechanisms. In other words, capacity control was achieved by the reset

[1] You can download a copy of this bulletin at http://www.av8rdas.com/mcc-powers-bulletins.html if you want to learn more.

schedule and fine tuned with the dampers. The valves were there only to totally shut down the elements on one face of a building as a limit control. For instance, on a cold but sunny day, the South face of the building may experience enough solar gain to cause it to over-heat for a while in the afternoon if the finned tube remains active, even thought the North, East, and West sides of the building need the heat since they have no direct solar exposure.

In addition, even if the control valve was properly sized for modulating control, as can be seen from Figure 8, modulating flow is not a very effective way to achieve it with finned tube radiation.

Lower Supply Water Temperatures = Energy Savings

Parasitic Losses

Another benefit to lowering supply water temperatures down from the design temperature when the design temperature is not required is that the parasitic losses from the piping network serving the FTR elements will be reduced.

Most people have an intuitive understanding of this; if you tell someone you are going to make the water leaving a boiler less hot, they will likely conclude that in doing that "the boiler does not have to work so hard" and thus will save energy.

While it's true that by making lower water temperatures the boiler will not be "working as hard" as it would have to make higher water temperatures, it is important to recognize why that is. More specifically, if in fact the desired building temperature is going to be maintained, then, for a given outdoor condition, the load will not have changed. You can see that by studying Equation 1.

But if you can meet the load with cooler water, that means that the losses in the piping serving the FTR elements will be reduced. These losses are frequently called parasitic losses because they are often undesirable in the context of accomplishing the end goal of heating the building. But in facilities like the Bureaucratic Affairs Building, they are a "necessary evil" that is the result of running the piping in the ceiling space.

The Core of the Building Requires Cooling Year Round

More specifically, the ceiling space is a return air plenum and the return air is being circulated by an air handling system that is actually providing cooling to the core of the building. Bear in mind that for most of our facilities, we need cooling year-round because the things we do in the facility generate heat. If we are in the core of the facility and the walls around us are not exterior walls, then the temperature is going to go up unless we actively do something to remove the heat.

Economizer equipped air handling systems circulate cool outdoor air in the winter to accomplish this without using mechanical refrigeration. In the summer, mechanical refrigeration cools the air. Either way, the heat in the occupied zones warms up the air. If that warm air goes through a ceiling plenum that has hot water piping in it, then the losses from the piping end up in the air and become a part of the cooling load.

If we reduce the losses from the piping by lowering its temperature to the level required to serve the load condition that exists at the time (vs. the design load condition), we save energy at the boiler even though the heating load - the energy required to offset the losses through the walls - did not change and we are meeting it. In addition, since the cooling process does not need to remove the losses that entered it via the return air steam, we save energy in the cooling process also.

A Subtle Point

For savings calculations, it's important to recognize that sometimes, the parasitic losses are not as important as they are other times. For instance, if you review the narrative describing the Bureaucratic Affairs Building and its history, you will discover that originally, there was no mechanical cooling and that the return system was ducted.

That means that in the winter, to some extent, the parasitic losses from the piping in the ceiling probably helped heat the building, especially on the 2nd floor given the roof load that would exist there. And since there was no mechanical cooling the losses in milder weather were picked up "for free" by the economizer cycle; it just brought in a bit more outdoor air than it would had the losses not existed.

Finally, since the original building did not have any reheat processes, the hot water system was shut down once it got warm outside. As a result, they parasitic losses went away and in the summer weather, the cooling provided by the economizer was not compromised at all by them.

The 1985 renovation made these losses more significant when it created a ceiling return plenum, putting the losses directly in the return air stream. And the requirement for reheat meant the piping would be hot on a year round basis, and thus the losses would to impact both the economizer cooling cycle as well as the mechanical cooling cycle.

Losses from Insulated Pipe can be Significant.

Thanks to the North American Insulation Manufacturer's free software tool called 3EPlus[2], it is easy to estimate how much energy would be saved by reducing the supply temperature in a hot water piping system as can be seen from Figure 10.

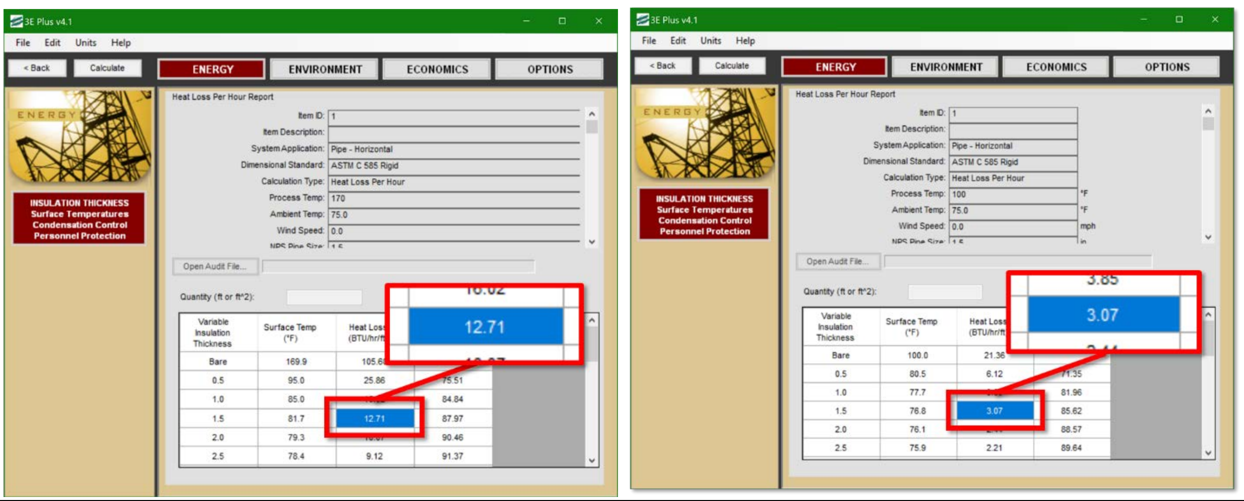

Figure 10 – Energy Loss from a 1-1/2 line with 1-1/2 inches of insulation at 170°F (left) and 100°F (right) calculated using 3EPlus

As you can see, using 100°F water instead of 170°F water during load conditions where you can meet the load with the lower water temperature reduces the parasitic load by over 75%.

There can be a surprising amount of pipe in a building. A 26-story high-rise hotel I am familiar with has in the range of 5-7 miles of hot water piping in each of the guest room towers serving the guest room fan coil units. So saving 10 Btu/hr per foot of pipe turns into a big number pretty quickly.

If you open up the model and grab the electronic tape measure and measure the hot water piping network length for everything but the piping running along the walls with the FTR elements in it, you will discover that there is about 1,080 feet of pipe mains (not including the run-outs to the VAV terminals) that will be hot but

[2] You will find a link to 3EPlus along with other resources associated with assessing the savings generated by applying insulation at http://www.av8rdas.com/insulation-savings-tools.html.

not putting heat where it is needed. So significant savings can be achieved by adding the reset schedule. The trick, aside from figuring out the logic, is figuring out "how low you can go" in terms of resetting the supply water temperature.

Adding a Reset Schedule to Solve the Comfort Problems and Save Energy

Reset Schedules and the Equation of a Straight Line

In its most fundamental form, a reset schedule is a mathematical relationship that calculates a set point based on some other parameter and takes on the form of an equation for a straight line (Equation 2).

$$Y = m \times X + b$$

Where:

$Y =$ The dependent variable, a function of X

$m =$ The slope of the line; $\frac{\Delta Y}{\Delta X}$

$b =$ The Y axis intercept; i.e. the value of Y when X=0

Equation 2 – The Equation of a Straight Line

For our application, we want to come up with a set point for the hot water supply temperature based on the outdoor air temperature. That means that for our purposes, we would define the variables in Equation 2 as shown in Equation 3.

$$Y = m \times X + b$$

Where:

$Y =$ Hot water set point, °F

$m =$ The change in set point that will be generated for every unit change in outdoor air temperature, or $\frac{\Delta Y}{\Delta X}$, or $\frac{\Delta SetPoint}{\Delta OutdoorTemperature}$

$b =$ The set point when it is 0°F outside

Equation 3 – Hot Water Supply Temperature Set Point as a Function of Outdoor Temperature

Determining the First Point on the Reset Schedule Line

We can define a line by knowing two points that lie on it and we already know one of them from the design documents.

Specifically, we know that the original designer anticipated requiring 170°F supply water on the design day. So, all we need to do is look up the winter design condition for Golden Girl, Missouri (the location of the Bureaucratic Affairs Building) and we will have our first point.

Despite being a college town, Golden Girl is a very quaint and quiet place, known for the exquisite beauty of the rolling hills that surround it. As a result, out of fear of becoming a sort of mecca for baby boomers, in 1954, the City Council passed a resolution limiting the size of the font used for the town's name on a map to 1 point. As a result, it is unlikely that you will find it if you go looking for it on a map of Missouri.

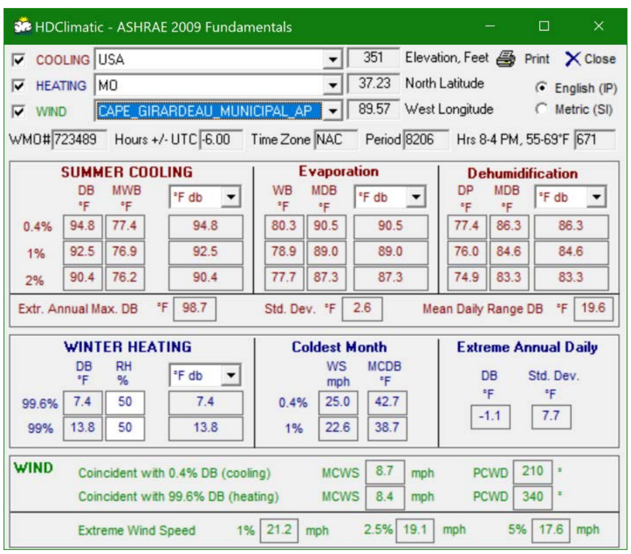

Figure 11 – St. Louis, MO Design Conditions

However, having spent many years of my life in Missouri and as a result, being somewhat familiar with the state, and despite only having discovered Golden Girl after moving to Oregon, I can tell you that it is west of St. Louis, on the general route to Jefferson City. So, it would be reasonable to use the St. Louis or Jefferson City, Missouri design conditions to develop our reset schedule. Towards that end, I have provided the St. Louis conditions in Figure 11 for your reference.

Incidentally, if you are wondering how you would find this sort of information in the general case, frequently an internet search will give you the information. But, if you procure the free, PG&E psych chart and then upgrade it to the Professional version, you will find that the information is included in the package, along with a number of other useful tools (follow the link to find out more). In fact, that is where the image in Figure 11 came from.

If we select the most stringent winter design condition (the 99.6% value), then we have one point on our reset schedule line;

Y = Hot Water Set Point = 170° when X = Outdoor Temperature = 7.4°F

What Can You Do If the Finned Tube Make, Model, and Performance Characteristics Are Unknown?

Sometimes, in older building especially, the submittal information for the equipment that is in place has been lost or destroyed. This can seem like a major problem at first. But fortunately, it is the physical characteristics of the equipment that determines its performance.

That means that if you could not find the original finned tube manufacturer's name, make and model, you could take a few measurements, assume geometric similarity, and estimate the performance from a different vendor's data. The concept of geometric similarity assumes that if you know the physical dimensions for a piece of equipment that are the drivers behind the performance of the equipment, then a different piece of equipment with similar physical dimensions will likely have similar performance.

For the finned tube radiation on our project, the heat transfer is driven by the size and shape of the fins, the size of the pipe the fins are mounted on, the fin spacing, the water temperature, the ambient air temperature, and the flow rate. That means you could:

- Measure the pipe diameter, and
- Measure the fin size, and
- Measure the fin spacing.

Then you could find a vendor with a product that had similar dimensions and use the design flow or measured flow rate for the existing elements along with the hot water supply temperature and ambient air temperature entering the element to come up with an approximation of how the elements on the project would perform.

Determining a Second Point on the Reset Schedule Line

To come up with the second point on our reset schedule line, we will need to do a bit of engineering based on the known performance of the finned tube radiation equipment (Figure 7) and the assumption that the perimeter heating load is directly proportional to the outdoor to indoor temperature difference (Equation 1).

More specifically, we know from the design data that the finned tube elements we are working with will produce 939 Btu/hr/foot of element with an average water temperature of 170°F for the run of elements. You could determine this from the data tables the manufacturer provides or just do it graphically as shown in Figure 12.

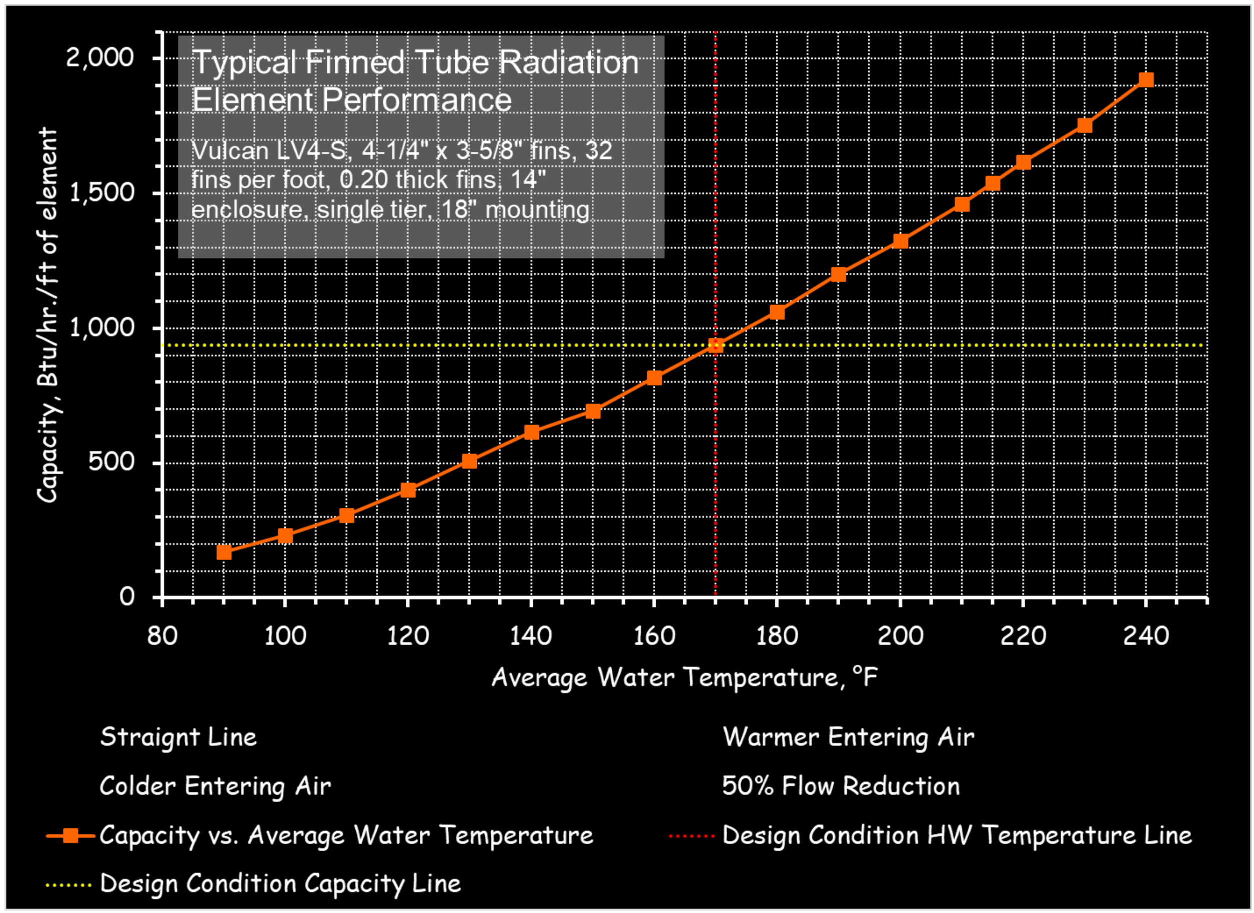

Figure 12 – Finned Tube Design Day Performance

Having established the unit capacity of the elements on the design day, and knowing that the perimeter load is directly proportional to the outdoor to indoor temperature difference across the wall (Equation 1), we can calculate the unit perimeter heating capacity required by the building on a unit length, per degree F basis as shown in Equation 4.

Given:

$$Q = U \times A \times \left(t_{Inside} - t_{Outside}\right)$$

and knowing the FTR design selection point:

$t_{Outside} = 7.4°F$
$t_{Inside} = 72°F$
$Q = 939 \frac{\text{Btu}}{\text{hr-ft}}$ when supplied with 170°F average hot water temperature of the length of run

we can say on a unit length basis:

$$939 \frac{\text{Btu}}{\text{hr-ft}} = \left(\frac{U \times A}{L}\right) \times \left(72°F - 7.4°F\right)$$

Where L is the total length of FTR element provided to offset the perimeter load.

Solving for $\left(\frac{U \times A}{L}\right)$:

$$\left(\frac{U \times A}{L}\right) = \left(\frac{939 \frac{\text{Btu}}{\text{hr-ft}}}{\left(72°F - 7.4°F\right)}\right) = 14.5 \frac{\text{Btu}}{\text{hr-ft-°F}_{\Delta t_{in-out}}}$$

Equation 4 – Unit Capacity of the Finned Tube Elements

We now have a metric to use to calculate the perimeter load at temperature differences other than the design condition. That in turn allows us to determine the water temperature that would need to be supplied to the FTR element to handle that load and that water temperature becomes the second point on our straight line reset schedule.

Mathematically, any indoor to outdoor temperature difference other than the design condition would work. But logically speaking, it makes sense to select a condition where the need for perimeter heat would be minimal, perhaps a temperature near the balance point of the building for example.[3]

If we use 55°F to establish the second point on our reset schedule, the result of the calculation is as shown in Equation 5.

$$\text{Load at 10°F below the balance point} = 14.5\frac{\text{Btu}}{\text{hr-ft-}\cancel{°\text{F}_{\Delta t_{in-out}}}}\times\left(72°\cancel{\text{F}}-55°\cancel{\text{F}}\right)=246.5\frac{\text{Btu}}{\text{hr-ft}}$$

Equation 5 – Perimeter Heating Load per Foot at 55°F with an indoor design temperature of 72°F.

Now that we know the load requirement, we can use the FTR manufacturer's data to look up the water temperature we needed to meet it as illustrated in Figure 13.

3 The balance point of a building is the outdoor temperature at which the energy gains on the perimeter due to lights, people, equipment, solar radiation and other sources exactly matches the energy losses through the envelope. In other words, the heating load is "balanced" by the internal gains. For most buildings with an indoor design target temperature in the low to mid 70°F range, the balance point will be in the 60-70°F range with 65°F being a common value selected.

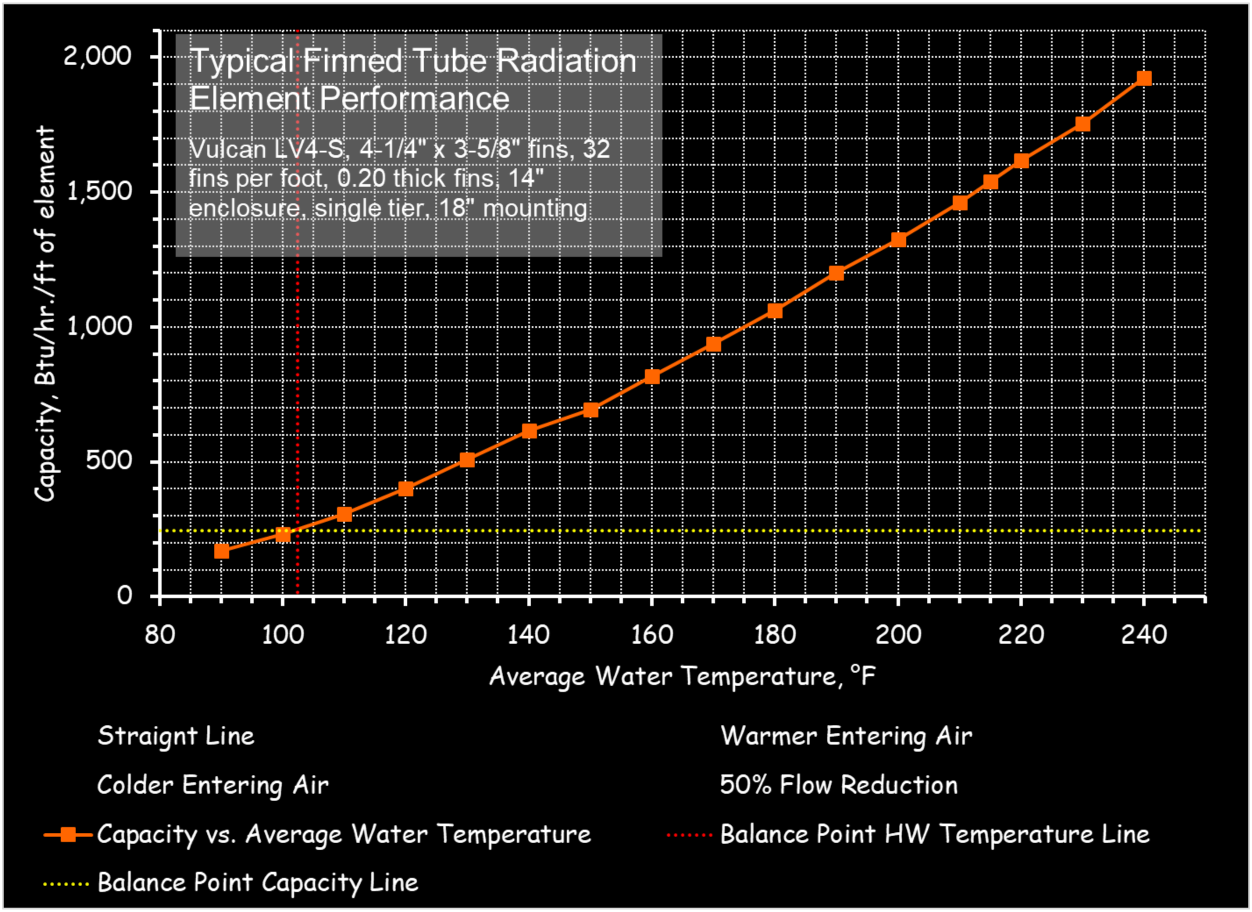

Figure 13 – Hot Water Temperature Required for the Load at 55°F Outside

We now have a second point on our reset schedule line;

Y = Hot Water Set Point = 102.5° when X = Outdoor Temperature = 55°F

Determining the Slope of the Reset Schedule Line

For some control systems, you don't have to develop the equation for the reset line. You just need to tell the system two points on the line and the internal algorithms do the rest of the math for you. That means that for some of the systems you may work with, we already have developed the information we need to program the reset schedule.

But for other systems, especially legacy systems, you need to program the reset schedule equation into the system. That means we need to take the information we have generated thus far and derive m (the slope) and b (the Y intercept) from it.

As you recall from Equation 3, the slope or "m" for the reset schedule line is simply the change in set point that will be generated for every unit change in outdoor air temperature. We can use the two points we have identified on the reset schedule line to come up with this, as illustrated in Equation 6.

$$m = \frac{\Delta Y}{\Delta X} = \frac{\Delta \text{ Set Point}}{\Delta \text{ Outdoor Temperature}}$$

Given:

Point 1 - $Y = \text{Hot Water Set Point} = 170F°$
$X = \text{Outdoor Temperature} = 7.4°F$
Point 2 - $Y = \text{Hot Water Set Point} = 102.5F°$
$X = \text{Outdoor Temperature} = 55°F$

Then:

$$\frac{\Delta Y}{\Delta X} = m = \frac{(170 - 102.5)°F_{HWST}}{(7.4 - 55)°F_{OAT}} = \frac{(67.5)°F_{HWST}}{(-47.6)°F_{OAT}} = -1.42\frac{°F_{HWST}}{°F_{OAT}}$$

Equation 6 – Determining the Slope of the Reset Schedule Line

Now that we have established the slope of the reset schedule line, we can calculate "b", which is the Y intercept for the line a.k.a. the value of Y when the value of X is zero by using one of our points and the slope we have calculated and solving the equation of a line for the "b" value as illustrated in Equation 7.

Given:

$$Y = m \times X + b$$
$$m = -1.42 \frac{°F_{HWST}}{°F_{OAT}}$$

Solving for b:

$$Y = (-1.42 \times X) + b = b - (1.42 \times X)$$
$$Y + (1.42 \times X) = b$$

Substituting the first point on our reset schedule for X and Y

$$b = 170 + (1.42 \times 7.4) = 180.51$$

Equation 7 – Determining the Intercept of the Reset Schedule Line

We now have all the information we need to write the equation for our reset schedule, which results in Equation 8.

Given:

$$Y = m \times X + b$$
$$m = -1.42$$
$$b = 180.51$$

Then:

$$Y = (-1.42 \times X) + 180.51$$

Or

$$HWSetPoint = (-1.42 \times OAT) + 180.51$$

Equation 8 – Our Reset Schedule Equation

Verifying Our Equation

The need to check my math is something I remember being emphasized most of my life, starting somewhere between 1st and 3rd grade when either Mrs. Mack, Mrs. Naily, or Ms. Dimperio – I can't remember who said it first – brought it up during a math lesson. More than once, taking that lesson to heart has saved me from an error, including as I write this. Bottom line, I am a firm believer in cross-checking things.

In this case, we can check ourselves by seeing if our equation will predict our second data point. If you try doing that, you get the result shown in Equation 9.

Given:

$$HWSetPoint = (-1.42 \times OAT) + 180.51$$
$$OAT = 55°F$$

Then:

$$Y = (-1.42 \times 55) + 180.51$$
$$Y = 102.41°F$$

Equation 9 -Checking our Work by Calculating the Hot Water Set Point for a 55°F Outdoor Air Temperature

That's close to the 102.5 associated with our second point; the difference can easily be attributed to rounding errors.

It's also important to remember that the numbers we are coming up with are a starting point and may not be the final numbers that are used once the logic improvement goes through the commissioning process and is fine tuned to the building and its occupants.

In other words, they are good and reasonable starting points that will get us in the right "ball park" because they are based on the physics of the building and the equipment. But there are a lot of other variables at play and part of the purpose of the commissioning process is to take our engineered requirements and adapt them initially and continuously to the day to day, year to year needs of the building and the occupants.

Considering the Summer Time Load Condition

Implementing the reset schedule we just developed would definitely save energy. But it may be possible to fine tune it a bit further if we explored how low we could go in the summer.

Specifically, once the outdoor temperature gets above the balance point for the building, we will no longer have a space heating load and the FTR elements should be shut down. At that point, the only load on the hot water system is the reheat load.

It is tempting to simply shut down the hot water system once there is no need for it to offset losses through the envelope. However, if:

- You recall that the main goals of our building systems are to deliver a clean, safe, comfortable, productive environment, and
- You recognize that those goals involve providing temperature and humidity control, and
- You realize that on a multiple zone system, for a number of reasons, you can have a condition where:
    a. The supply temperature from the air handling unit can not be raised, either because it is needed for dehumidification purposes or because another zone on the system requires the cold air for legitimate cooling, and/or
    b. The minimum flow rates to zones that will overcool at the current supply air temperature can not be further reduced without under-ventilating the zones in question.

As a result, reheat becomes necessary if we are going to keep things safe (maintain the required ventilation rate) and comfortable (keep the temperature under control).

That means that for existing building commissioning our goal is generally not to shut down a hot water system serving reheat loads, at least not carte' blanch. Rather, it is to understand how to:

- Minimize the reheat loads so they are as low as possible, and

- Optimize the hot water temperatures serving the reheat loads to minimize parasitic losses and maximize the opportunity to serve the loads with recovered energy, and
- Consider alternate ways to serve them, perhaps with recovered energy from the cooling process or with solar energy.

Occasionally, if we do all those things just right, under certain load conditions, we may discover that we actually can shut down the reheat system for a while. But that should be an informed decision based on all the factors mentioned above, *not* a decision based on the outdoor temperature being above the balance point for the building, meaning its hot outside and therefore, you don't need heat.

Heating vs. Preheat vs. Reheat

Just to make sure we "are on the same page", I am going to insert the technical definitions of a heating process, a preheat process, and a reheat process so you can compare them.

Heating

Heating is a process that adds energy. For a space, this is often accomplished by circulating air through it at a temperature above the required set point. For an airstream, this is often accomplished by passing it over a surface that is above the required supply temperature.

Preheat

Preheat is process that heats a fluid stream to prepare it for a subsequent HVAC process. In air handling systems, this process is used to raise subfreezing air above freezing to protect water filled elements down-stream from damage due to freezing.

There are several definitions related to preheat that you should be aware of including:

- *Freezing*, which is a condition that occurs when water is cooled to the point where it changes phase from a solid to a liquid.

  When this happens, the volume of the water actually increases a bit because of how the molecules line up to form the ice crystals. That means if the water is trapped in a pipe or a tube in a coil, the expansion can rupture the pipe or tube.

- *Water Damage*, which is a condition that occurs after frozen water contained in a HVAC coil changes back to the liquid phase.
- *Expletive*, which is a generic reference to the field terminology used to describe and discuss water damage when it occurs.

Reheat

Reheat is a process that uses heat to warm air being delivered to a zone to prevent over cooling.

- The temperature of the air was set by the need to hit a dehumidification target or by the requirements of another zone, so it cannot be raised at the central system.
- The volume cannot be reduced because it has been set to assure proper ventilation (contaminant control).

Bottom Line

In the limit, reheat will raise the supply air temperature upwards towards the zone temperature but not above it. In other words, reheat is just trying to make the air just a little less cold than the temperature coming from the central system. But the zone still needs cool air because it has more energy coming into it from lights, people, equipment, etc. than leaving it.

If there was more energy *leaving* the zone than coming into it from the lights, people, equipment, etc. then you would need to heat the zone by delivering air that was warmer than the targeted zone set point.

The *Functional Testing Guide* has more information comparing these processes in *Chapter 5 – Preheat*, of the *Air Handling System Reference Guide, Table 5.1* and related discussion.

Determining How Low You Can Go in Warm Weather

Once the outdoor temperature is above the balance point for the building, the hot water we supply only needs to be warm enough to make the air less cool for the zones where the flow rate we are delivering is at the minimum allowable flow for the zone and the air coming from the AHU at that flow rate would over-cool the zone at that level of flow.[4] Typically, under these conditions, the air supplied from the central AHU will be in the low 50°F to mid 60°F range.[5] So intuitively, we can see that we would only need to supply water that was warmer than those temperatures to transfer some energy to the air to reheat it.

Asking the Building

One way (and my favorite way) to come up with this number is to ask the building. Joe Cook taught me this trick one day back in the mid 1980's. Joe was the maintenance foreman at Memorial Hospital in Carbondale Illinois, and he, Tom Stewart (the director of facilities) and I were standing in the central plant one July day contemplating a project that was about to start.

The topic of discussion had moved to how low the heating water supply temperature could be in the summer time. It had just dawned on me that it might be possible the one row reheat coils generally applied in the facility to deliver neutral or near neutral air when supplied with water in the 85-95°F range.

Certainly, you could not generate the design leaving air temperatures which were in the 105-115°F range using 200°F hot water. But, in the summer we only needed reheat (less cool air) not heat (air that was delivered warmer than the target space set point).

If the hot water system could provide reheat at the lower supply temperature, then it seemed possible that the reheat could be provided by recovering energy from the condenser water going to the cooling towers, which ran in the 95°F range in hot, humid weather. At this point, two things happened.

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4 Remember, in the scenario we are discussing, we can't raise the AHU leaving air temperature any higher because it is required for dehumidification purposes or because there are one or more zones that need the cooling capacity provided by that air temperature.

5 In many climates, going above 65°F can put you at risk for inadequate dehumidification, setting up mold and mildew problems.

And it is possible that the air could be cooler than 50°F. For example, in the cleanrooms I worked with at Komatsu, we delivered 46°F air in order to achieve the humidity level we needed in the space. But we were pushing the limits of what you could do with chilled water with our chillers running 38°F leaving water temperatures, which meant the refrigerant was sub-freezing. Any colder and we would have needed to use a glycol mix to ensure we didn't risk freezing the chiller tubes.

- Tom and I, being engineers, engaged in a discussion of the pro's, con's, technical merits, limitations, and practicality of modeling all the existing reheat coils on the site to determine their performance characteristics with 85-95°F supply water.
- Joe, accustomed operating in the real world, said "let's see when we get a cold complaint" and walked over to the hot water system temperature controller and turned it down 5°F, a process he repeated periodically for the next several days.

Joe's science experiment quickly revealed that the existing system could be expected provide a comfortable environment during the non-heating season with water temperatures in the high 80°F to low 90°F range if one or two reheat coils were replaced.[6]

Modeling the Coil

Truth be told, I complemented Joe's science experiment with some coil modeling just to be sure of what would happen under different conditions from what existed the day of the experiment. And for the purposes of the Bureaucratic Affairs Building model, I had no other choice.

As I mentioned under *Related Resources*, I have included the model with the supporting resources if you want to play with it. But bottom line, it indicated that with 90°F entering water, a typical Bureaucratic Affairs Building reheat coil would raise 53°F air to 62°F; in other words, the 90°F water would make the air to the zone with an active reheat coil a little less cool, which is all that we need in the summer.

So that gives us a starting point for the summertime hot water supply temperature set point. We can use Joe's approach to fine tune it during the commissioning process. And training operators about that will be important of course so they can continue to optimize it as time moves on.

In terms of our logic, one approach would be to figure out the outdoor temperature that would give us a 90°F set point and simply use that as the second point in our reset schedule equation. Running the math out reveals that by the

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[6] If you want the full story, I include it in a paper Tom and I wrote for ACEEE titled *Making Energy Intensive HVAC Processes More Sustainable via Low Temperature Heat Recovery*.

time the building reaches the balance point (approximately 65°F), the reset schedule will have driven the hot water set point down into the desired range.

Specifically, our reset schedule will have adjusted the hot water set point to 90°F by the time the outdoor air temperature approximately 64°F (see Equation 10).

Given our reset equation:

$$HWSetPoint = (-1.42 \times OAT) + 180.51$$

Solving it for OAT

$$OAT = \left(\frac{HWSetPoint - 180.51}{-1.42} \right)$$

Then with $HWSetPoint = 90°F$:

$$OAT = \left(\frac{90 - 180.51}{-1.42} \right)$$

$$OAT = 63.73°F$$

Equation 10 – Calculating the OAT That Resets the Hot Water Temperature to 90°F

So, one option would be to just run with our reset equation and fine tune the two points defining the line as needed based on what the building tells us.

But, if we wanted to provide more flexibility, or if things didn't work out so "nicely" (for instance at 65°F our reset schedule still had the hot water set point up around 120°F), then we might want to add some logic that applied a fixed set point of 90°F at or below the balance point for the building.

Of course, with the added flexibility comes some added complexity in the logic. That means the decision to do it is a judgement call. The right answer is in there someplace and we will get to it by balancing all the factors that come into play to find the <u>*best*</u> right answer. And all the potential right answers are based on the physics of the building; that's what makes them right answers.

Addressing a Few Details

Capping the Reset Schedule

No matter what the decision is regarding how to accommodate the summer set point, it would be desirable to cap the reset schedule at both ends.

Low End, Warm Weather Cap

Without a low-end cap, on a 105°F day (which can happen in Golden Girl Missouri assuming it really is similar to St. Louis and Jefferson City; see Figure 14), the reset schedule would push our hot water set point down to about 31°F in theory.

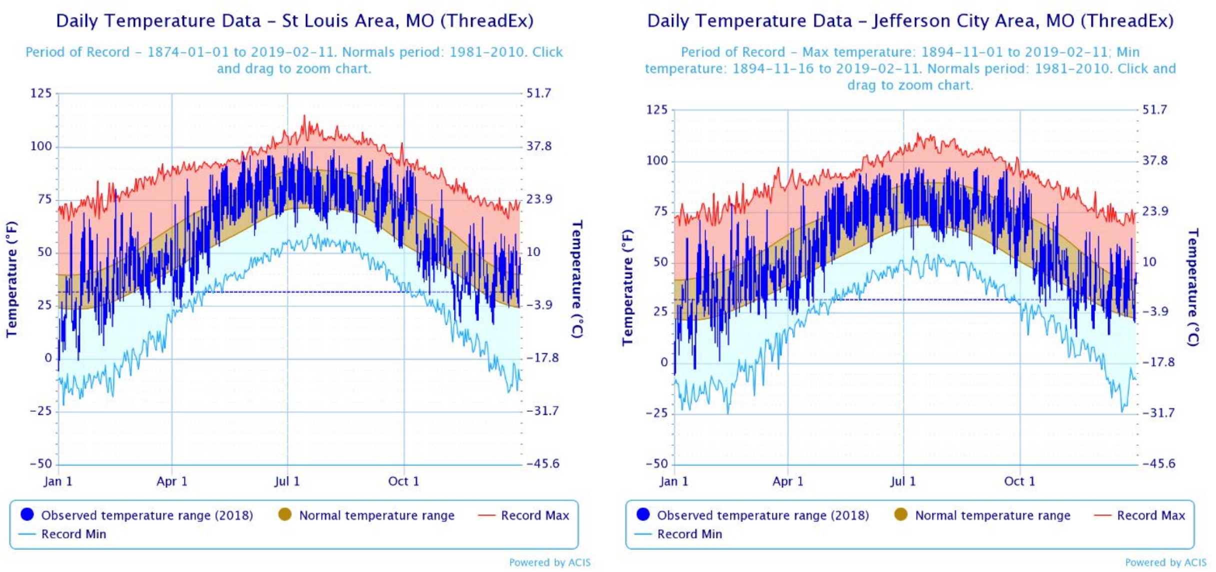


Figure 14 – St. Louis, MO and Jefferson City, MO actual temperatures vs. normal and the extremes for 2018.

That won't happen with out refrigeration of course. But at some point, our ability to do meaningful reheat would be diminished if we didn't cap the reset schedule on the low end. Essentially, that is what we would be doing if we added logic that uses a fixed set point once we reach the balance point.

High End, Cold Weather Cap

Capping the upper end of the reset schedule has more to do with safety than anything else. There are two hazards associated with high hot water temperatures. One is the obvious; burns if you come into physical contact with the hot pipe surface. It is possible for our skin to be damaged if we com into contact with surfaces above about 110°F.

For the FTR system, the covers in the occupied spaces and the insulation on the piping elsewhere provides a pretty good measure of protection. But you still would want to be careful around any uninsulated fittings and valves, like the drain valves and vents for instance.

The other hazard is subtle but significant. Specifically, if the set point goes above 212°F (at sea level), if you drain water from the system through a vent or drain port, all of a sudden, you are dealing with steam, not water. In other words, if we reset above the boiling point of water at the ambient atmospheric pressure, then when we open a vent or drain valve, the water will flash to steam.

Aside from their being a risk of scalding, there is a lot of potential force involved. That is because if you flash a cubic inch of water to steam at atmospheric pressure its volume increases by a factor of 1,600. That is a big deal. So, if you don't need to reset above 212°F to get the capacity you need (and some systems actually do need to do that in extreme climates) then there is some merit in considering a cap at or below 212°F.

One approach to the high-end cap is to simply set it just below the saturation temperature for the local altitude. You can figure this out using a steam table and the pressures associated with the standard atmosphere. But a more elegant solution would be to cap it at the set point that would be required by the extreme on record for the location the system is at.

If we use the St. Louis climate data in Figure 11, the extreme on record is -1.1°F with a standard deviation of 7.7°F. So, it might be reasonable to cap the reset schedule at the set point associated with -8 to -10°F. The historical data in Figure 14 indicates it could occasionally be even colder than that, maybe as cold as-20°F to -25°F.

If we do the math using the ASHRAE data, it sets the cap at 190-195°F. If we do it based on the extremes on record, then the cap is more like 208-216°F. Deciding what to use is another engineering judgement call. For this facility, I would probably set the cap below 212°F in the interest of safety.

Considering the Source of Heat

Steam Heat Exchangers

So far, our discussion has been about the logic for resetting water temperatures in the system illustrated in Figure 1 and Figure 2. Specifically, the heat source is a heat exchanger that is supplied with steam from the campus distribution system. That means that we don't have to worry about condensing flue gasses in a boiler that was not designed to deal with that and that we can vary the flow significantly without any cause for concern.

Traditional, Non-condensing Boilers

If we had a traditional, non-condensing boiler instead of a steam heat exchanger, then the system diagram changes (Figure 15) as does the specifics of the logic we would use to control it. There still would be benefit in resetting the water temperature in terms of reducing parasitic losses. But we would need to do it in a way that kept the water temperature to the boilers above the temperature that would cause the water vapor in the flue gas to condense.

For gas fired boilers, that usually means an entering water temperature no lower than 130-140°F although some manufacturers can go as low as 105°F. For oil fired boilers, the number is more like 160°F. Most manufacturers have minimum flow limits that will also come into play.

The point is that if boilers provided the heat for the system, then there are several additional factors that come into play relative to using a heat exchanger. And all of those factors will be very specific to the make and model of the boiler and the fuel that is used. But across the boards, the warranties I have seen state that if you go below it, then the boiler warranty is null and void.

One way of keeping the boilers hot while lowering the distribution temperature (as can be seen from Figure 15) requires:

1. A separate piping circuit with an independent pump, perhaps even an independent pump for each boiler.
2. Boiler control based on the manufacturer's requirements.
3. A bypass and three-way valve that allows the distribution loop to be operated at a temperature below the boiler loop temperature.

The basic logic we have discussed for the heat exchanger would be used to modulate the three-way valve to mix cool return water from the loads with the warm water from the boilers to hit the desired set point and all of the things we considered would still apply.

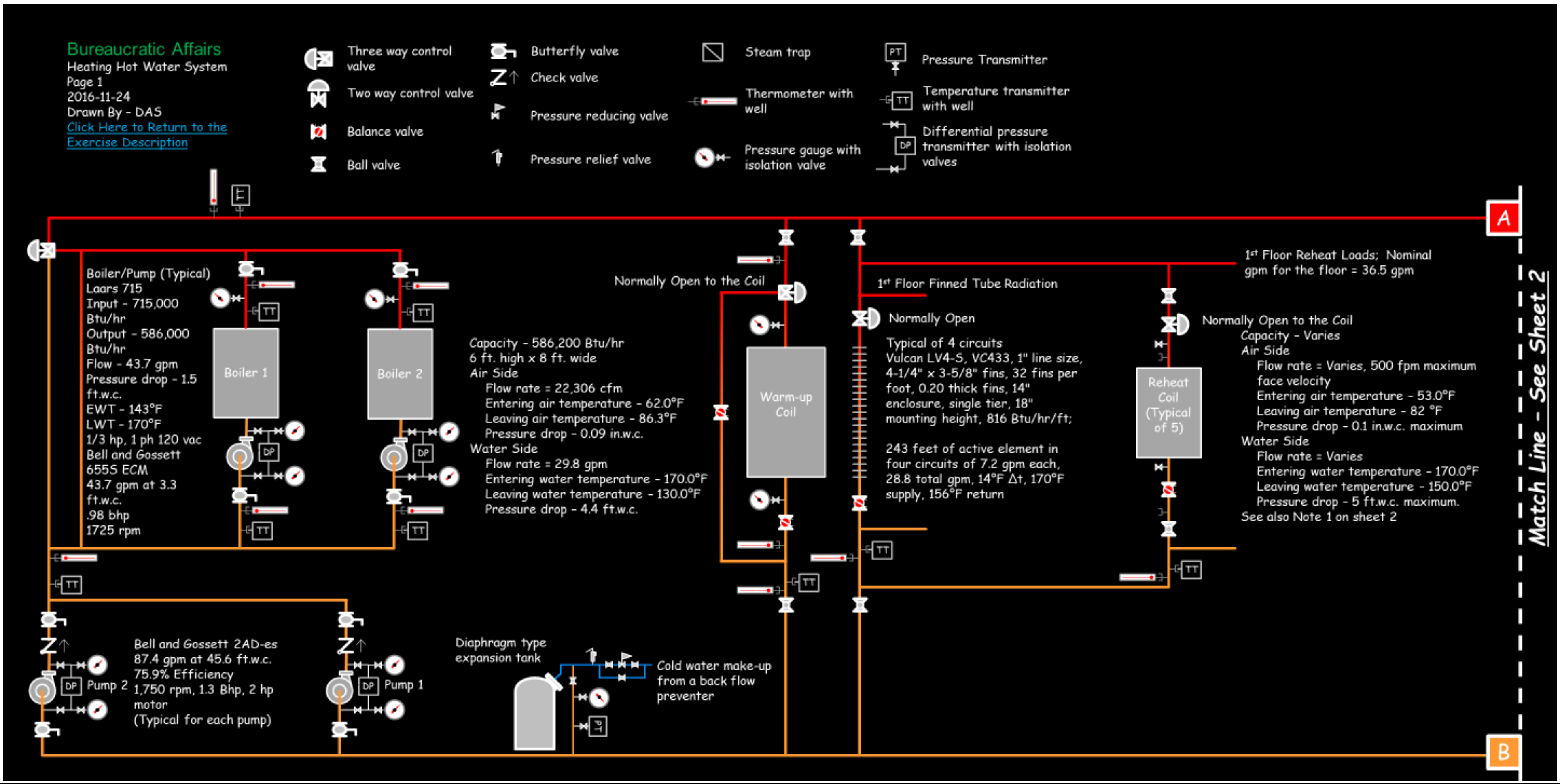


Figure 15 – Hot Water System Diagram with Non-Condensing Boilers

Condensing Boilers

If the system was served by condensing boilers instead of a heat exchanger the system diagram would look more like what is shown in Figure 16.

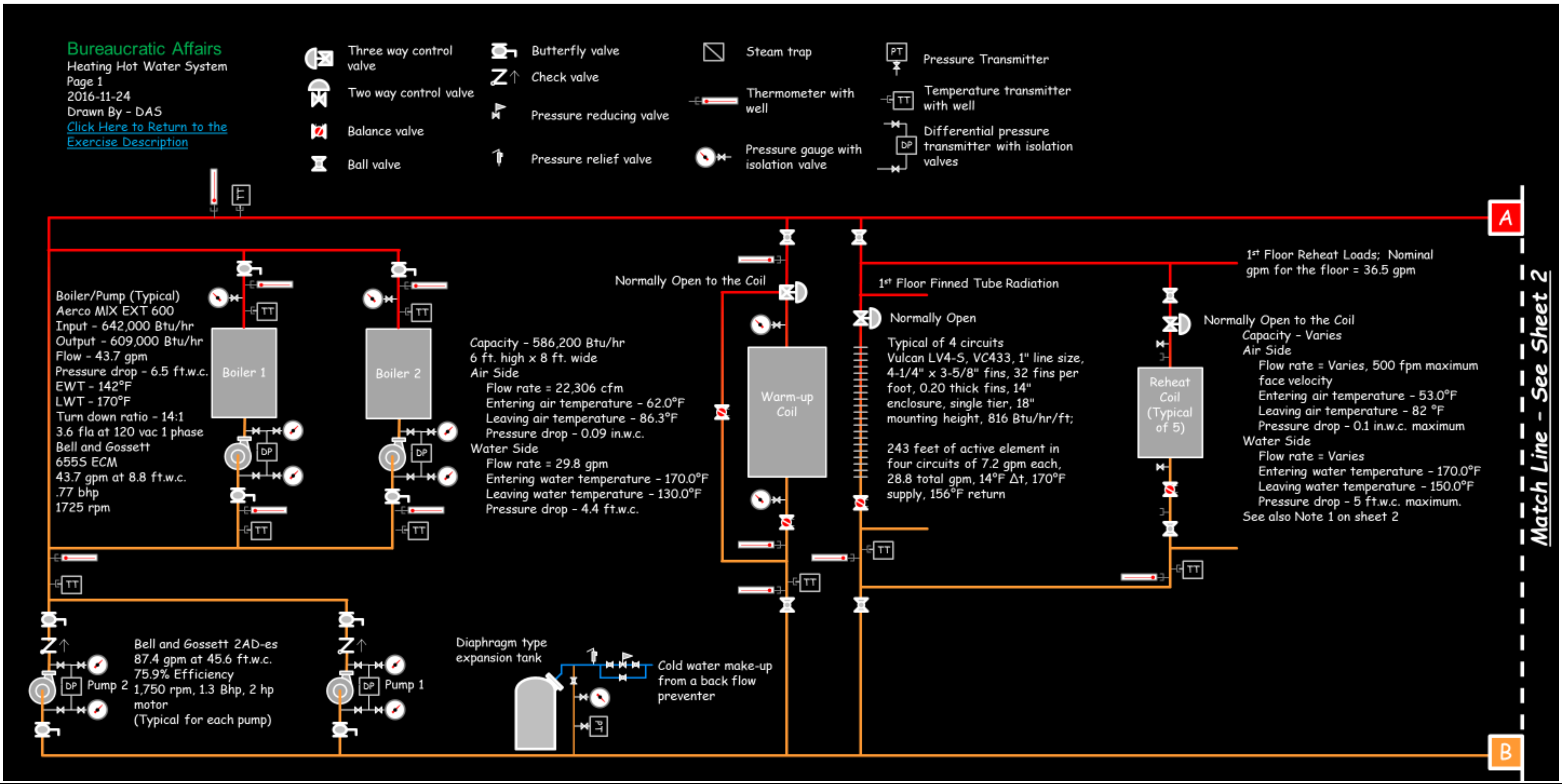


Figure 16 - Hot Water System Diagram with Condensing Boilers

As you can see, the boilers would likely need to be provided with pumps to maintain flow above the manufacturer's minimum flow limit. But the issue associated with avoiding condensation of the flue gasses goes away.

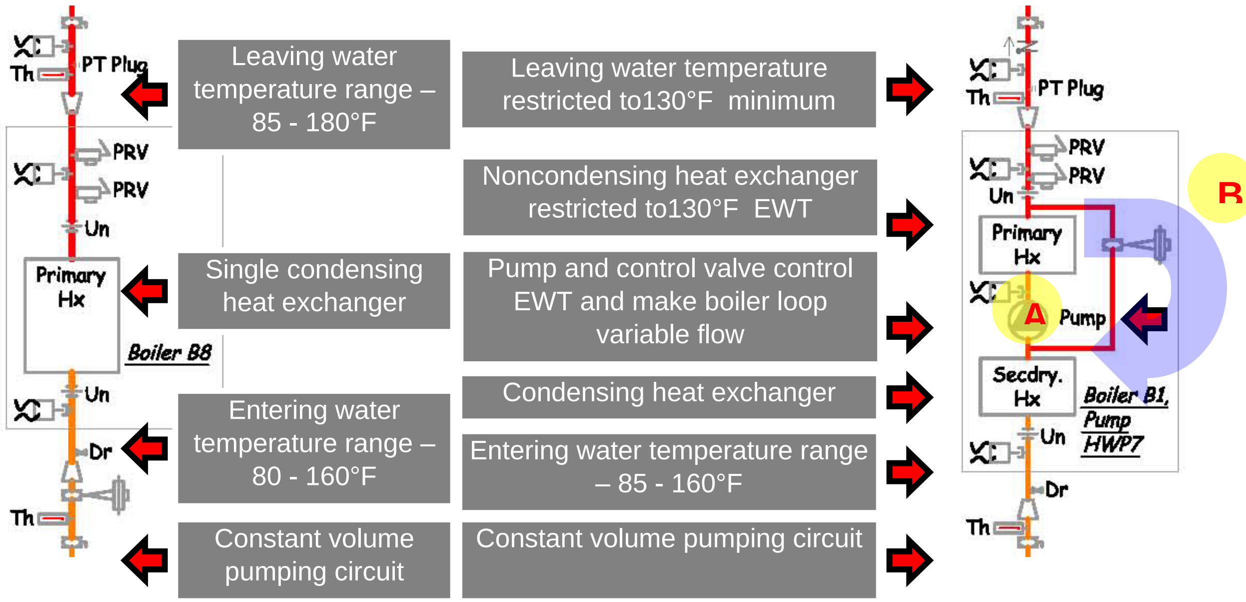
Condensing water out of the flue gas is the mechanism that condensing boilers use to deliver the high efficiency levels that are associated with them. But different manufacturers have different approaches to this. That means they are not all created equal, as can be seen from **Error! Reference source not found.**. In turn, that means that you can not necessarily substitute one condensing boiler for the other with out considering the nuances in terms of how they will interact with the system they serve, both from a temperature control standpoint and from a flow management standpoint.

Error! Reference source not found. was taken from a forensic engineering report I did where I dug into why 5 of 8 new boilers had failed with-in the first 1-3 years in service. There were several issues uncovered, but one of the primary reasons for the failure was that the basis of design boiler for the system was similar to the boiler on the left in the figure.

But a boiler like the one on the right in the figure was substituted. As a result, the system was unable to achieve several the design targets including:

- Delivering low supply temperatures during the summer months, which would have facilitated using recovered energy for reheat and minimized parasitic losses.
- Inability to operate as a variable flow primary/secondary system. The system was essentially a variable flow primary, variable flow secondary system and the operation of the boiler pumps as they staged often was in conflict with what the distribution pumps needed to do in order to satisfy their control algorithm.

So bottom line to deliver the required temperature and flow on the distribution side of the system, you need to write your control logic in a manner that supports the energy conversion technology that was employed. In the case of the Bureaucratic Affairs Building hot water system, even though on the load side we needed a reset schedule that spanned a specific and predictable temperature range, the piping and pumping configuration and specific logic required to do it will vary with the nature of the source of heat.



The primary difference between the Aerco Benchmark BMK2.0 boilers (left illustration) that were the basis of design and the Lochinvar Intellifin IBM2000 boilers (right illustration) that were actually furnished is that the Aerco units employ a single heat exchanger, rated and designed for condensing operation. In contrast, the Lochinvar units employ two heat exchangers, one of which (termed the secondary heat exchanger) is rated and designed for condensing operation and one of which (termed the primary heat exchanger) is not. To protect the primary heat exchanger from damage due to the corrosive by-products associated with condensing operation, the Lochinvar boilers incorporate a circulating pump (A) and a control valve (B), arranged to ensure that the entering water temperature to the primary heat exchanger never drops below 130°F. This is accomplished by recirculating water from the boiler's discharge to the inlet side of the primary heat exchanger as indicated by the blue shaded arrow in the right illustration. For this approach to work, the boiler must be controlled so that the leaving water temperature from the primary heat exchanger is never below 130°F. As a result, a system that employs the Lochinvar units and must directly control for supply water temperatures below 130°F need to incorporate some other mechanism for achieving the supply temperature requirement while protecting the boilers. One common approach for accomplishing this is to provide the system with a three-way valve that allows water from the boiler loop to be mixed with return water from the system to achieve the required supply temperature. Since the Aerco boilers are rated to control directly for any set point from 50-190°F, the basis of design system did not in incorporate such a feature. As a result, when the Lochinvar boilers are applied in the basis of design system configuration, there is no direct method for controlling supply temperature to a set point of 130°F. Rather, the master controller charged with cycling the boilers to maintain a desired system supply temperature must try to find a combination of boiler settings that indirectly produces the desired result by forcing the distribution system into an over-flow condition (distribution flow exceeds boiler loop flow) while the individual boiler controllers work to prevent the entering water temperature to their primary heat exchangers from dropping below 130°F. This is a complex hydraulics problem at best and may be impossible to achieve under some

Figure 17 – Two Different Condensing Boiler Designs

Heat Source and the Value of the Saved Energy

The energy savings you will achieve by implementing the reset schedule will be very dependent upon the energy source also. For buildings using steam from a central plant, like the Bureaucratic Affairs Building, the value attached to the energy needs to consider:

- *The efficiency of the energy conversion process at the central plant.* If the plant is burning fuel in boilers to generate steam, the value will be different from what it is if the steam is generated by running the exhaust from a cogeneration turbine through a heat recovery boiler.
- *The type of fuel that is being used.* A plant burning natural gas will have a different fuel cost on per Btu basis as compared to a plant burning fuel oil or biowaste.
- *The losses in the distribution system.* Just like the piping in the building, the piping delivering steam from the plant to the building will have losses.

The distribution losses can be quite significant in an older system were the piping and it's insulation system is failing. EnergyStar's technical document on Site and Source energy factors suggests that the distribution line losses will be at least 7-8%. But on one site I was on recently with an aging, direct buried distribution system, the Owner was scrambling to try to figure out how to deal with measured losses of 40% between the central plant and some of the loads on the system.

When you run into a situation like that in an existing building commissioning process, it is tempting to feel like you just discovered a gold mine because of the compounding effect the distribution losses will have on the savings you achieve in the building. And there is an element of truth to that.

However, if the Owner is in the midst of making an improvement that will reduce the losses, it is important to gain a sense of the time line for the improvement and adjust your projections accordingly.

For instance, if I identified an improvement that would save energy in a building that was being served by a distribution system with 40% losses, but the Owner had a plan in place that would reduce those losses to 8% with-in the next year, then a project that had a simple payback in the range of 2 years based on 40% distribution losses might stretch out into taking 3 or 4 years to pay for itself.

That doesn't mean it is not worth doing the work. But if you presented it as a project having a payback of 2 years or less and it stretched out to 3 or 4 years due to improvements made in the distribution of energy, then you are misrepresenting the value of the project and your client may feel that you mislead them when the return on investment does not come in as anticipated.