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TOTAL SYSTEM EFFICIENCY: THE NEW DESIGN PARADIGM

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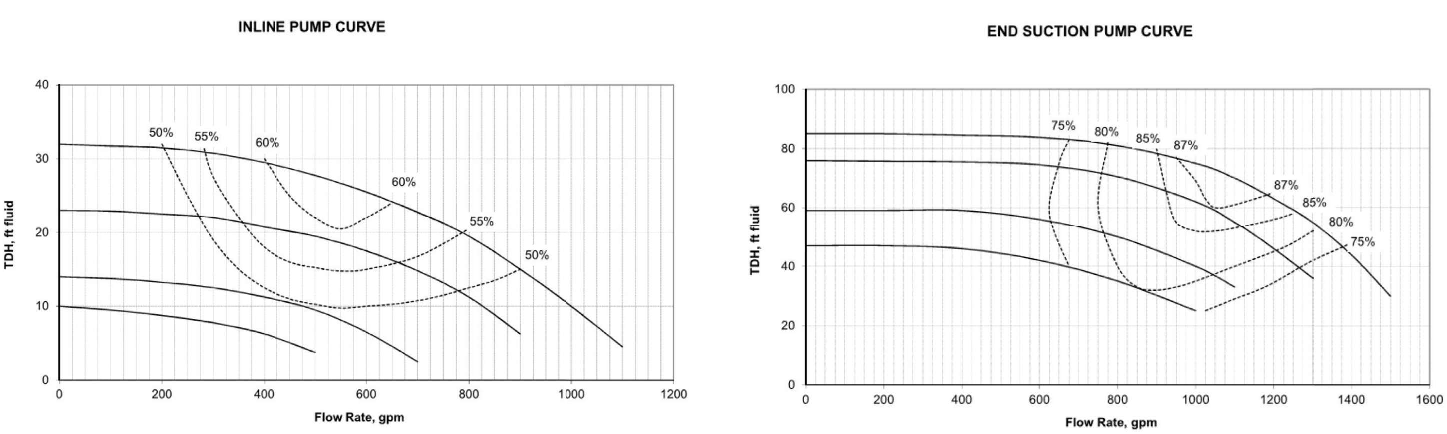
There are advantages and disadvantages to the new design paradigm of engineering a system with condensing boilers. Condensing boilers are very different from traditional boilers in both their operation and design; hence, there are several design considerations to keep in mind when incorporating condensing boilers.

ADVANTAGES OF THE NEW DESIGN PARADIGM

The previous paper titled “Total System Efficiency: Control Strategies & System Distribution” discussed at length the ability and preference for condensing boilers to operate in a variable-flow-primary pumping configuration compared to the traditional primary-secondary pumping configuration of non-condensing boilers. A high mass condensing boiler can operate in this configuration because of its ability to provide variable flow through the heat exchanger without concern for condensing the flue gases in the heat exchanger due to its robust, corrosion-resistant construction.

With a variable-flow system, the ability to utilize one set of pumps for all the piping within the hot water system is an advantage from both a first cost and operational cost consideration. The single set of pumps is designed for the entire system pressure drop, including the worst-case circuit at the coil including the heating coil, temperature control valve, isolation valves and balancing valves, in addition to the devices at the central plant, including the air separator, boiler, isolation valves, and buffer tank, if required, based on the system volume. To pump through all these devices, the pump head will vary based on the building and system; however, it will generally be a high-head pump in the range of 50 to 100 feet of head. Similarly, the flow for the system will be based on the boiler selection, building size, system ΔT, and heating-load calculations, and it will be a high-flow pump. For pump selection, it would be typical to use an end-suction, base-mounted pump that is maintenance-friendly, and combine it with high head and high flow, resulting in a more efficient pump compared to an inline pump as shown in Figure 1. Note the better efficiency at full- and part-load conditions.

Figure 1: Typical inline circulation pump with best efficiency at 62% compared to an end-suction pump with best efficiency at 89%.



Since these are the only pumps in the system, the additional set of pumps for the primary loop in the primary-secondary configuration are not needed as the function of pumping through the boilers is absorbed in the primary pumps. This results in first-cost savings as there are fewer pumps in the system to operate; fewer electrical connections to make during construction; and less piping, valves, and hydronic components. Similarly, since there are fewer mechanical, electrical, and control components, there is less space needed in the mechanical room, which enables more room for other building functions or reduces the building footprint, compounding the first-cost savings. Also, condensing boilers can run at a much lower hot water return temperature compared to a non-condensing hot water system that must maintain the hot-water-return temperature to the boiler above condensing conditions. This condensing boiler advantage equates to designing a system with a larger ΔT, which can further reduce pipe sizes and first cost.

In addition to first-cost savings, there are also operational cost savings that can be gained from operating with condensing boilers in the variable-flow-primary configuration. For the same reason fewer valves and smaller piping reduces first costs, a single set of pumps also reduces the pumping energy required. By operating with more efficient pumps, additional pumping can be achieved with less total-system horsepower. Similarly, by designing condensing boiler systems with higher ΔTs, system pump flows can be decreased, which enables equivalent heat transfer with less pumping and boiler energy.

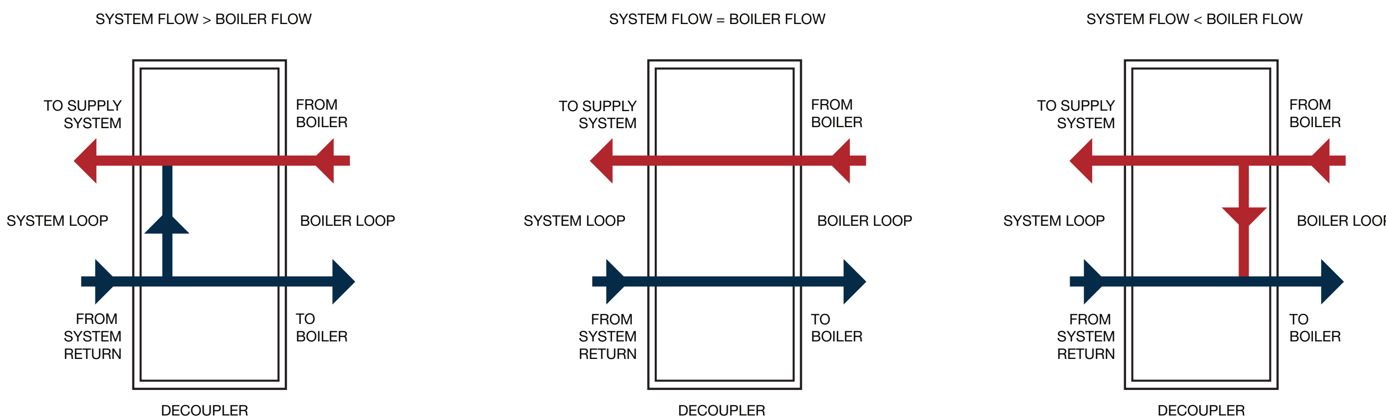
To demonstrate the benefits of a modern, variable-flow-primary condensing boiler system design compared to a traditional, primary-secondary, non-condensing boiler system design, see Table 1. This table provides a summary of the pumping energy required based on the system configuration.

Table 1: Comparison of boiler efficiencies, equipment quantities, and pump horsepower for condensing vs. non-condensing boilers.

	Two (2) 1500 MBH Condensing Boilers	Two (2) 1500 MBH Non-Condensing Boilers	Two (2) 2500 MBH Condensing Boilers	Two (2) 2500 MBH Non-Condensing Boilers
Boiler & System ΔT	140° – 100°	180° – 140°	140° – 100°	180° – 140°
Boiler Efficiency	92%+ depending on HWR temperature	88%	92%+ depending on HWR temperature	88%
Boiler Output	2760 MBH	2640 MBH	4600 MBH	4400 MBH
Primary Pump Flow Rate	138 GPM	66 GPM	230 GPM	110 GPM
Primary Pump Head	70 FT HD	20 FT HD	70 FT HD	20 FT HD
Primary Pump Power	3.44 BHP 5 HP	0.46 BHP x 2 3/4 HP	5.50 BHP 7-1/2 HP	0.80 BHP x 2 1 HP
Pump Efficiency	72%	75%	76%	71%
Secondary Pump Flow Rate	-	132 GPM	-	220 GPM
Secondary Pump Head	-	65 FT HD	-	65 FT HD
Secondary Pump Power	-	3.01 BHP 5 HP	-	4.82 BHP 7-1/2 HP
Pump Efficiency	-	72%	-	75.5%
Total Pump Power	3.44 BHP 5 HP	3.93 BHP 6-1/2 HP	5.50 BHP 7-1/2 HP	6.42 BHP 9-1/2 HP

Another benefit of the variable-primary-flow configuration is the mixing that has the potential to occur in the common pipe in a primary-secondary system. Depending on the flow rate in each respective system loop, the flow direction in the common pipe can reverse as observed in Figure 2. As shown, if the system distribution flow is greater than boiler flow, which occurs when system demand is greater than the boiler load, cooler hot water return mixes with hot water supply from the boiler loop and reduces the net hot water supply temperature that is distributed to the system. Conversely, if boiler flow is greater than system distribution flow, the hot water supply from the boiler will short cycle the system through the common pipe and return to the boiler, increasing the hot water return temperature back to the boiler. This reduces the boiler ΔT and sends a signal that the system is satisfied, which decreases the operating efficiency of the condensing boiler.

Figure 2: Flow direction in the primary-secondary common pipe based on boiler or system demand.

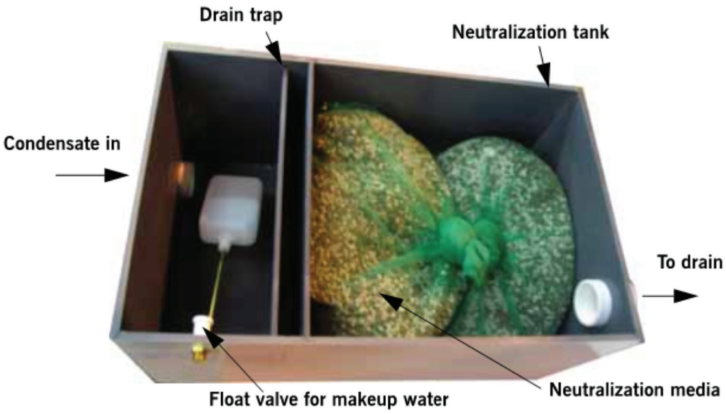


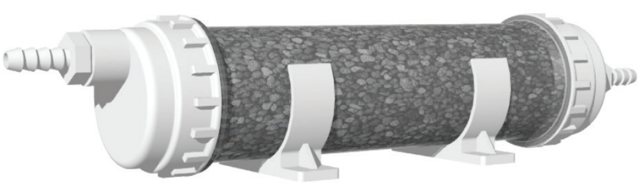
DISADVANTAGES OF THE NEW DESIGN PARADIGM

Despite all the advantages of condensing boilers, there are also some disadvantages that must be addressed, which can increase the first cost of the system. One area of consideration is the exhaust flue venting materials. Condensing boilers condense the flue gases and a majority of the heat is removed from the gases prior to discharging them to the atmosphere. This results in lower flue gas temperatures compared to boilers operating in a non-condensing mode. Although alternative stack materials are sometimes used, it should be noted that most have temperature limitations, and a stack temperature limit function should be utilized to protect the stack. If the temperature limit is exceeded, it will shut down the boiler. As the flue gases are condensed, the condensate is highly acidic and the venting should be constructed from materials that are resistant to corrosion. Because of this, standard venting used for non-condensing boilers is not an option. Condensing boilers also have the unique ability to operate at multiple design conditions such as fully condensing, or a condition where the system is operating out of its condensing range if hot water return temperatures are above the condensing point of the flue gas. Because of this, it is highly recommended to use venting that is constructed from stainless steel to protect the stack in all operating conditions and is listed for use with condensing appliances.

Another matter to note with a condensing boiler is the condensate that collects either during startup of a cold boiler or when the boiler is operating in the condensing mode. Condensing the flue gases is the intent of the design, but as the condensate collects in the boiler and the flue stack, the condensate must be discharged to a code-approved drain that is part of the plumbing system. Since the condensate is acidic, it is recommended to pipe the condensate through a condensate treatment kit, thereby neutralizing it prior to discharging it through the drain as shown in Figure 3. The kit requires routine maintenance because the neutralizing media must be replaced since it is used during the neutralizing process. Replacement frequency is a function of the amount of condensate that is produced by the boiler(s). Additionally, the materials of construction in the domestic plumbing system should be discussed with the plumbing engineer to confirm that the discharge is compatible with the piping material.

Figure 3: Condensate treatment kits with a condensate drain trap and neutralization basin or tube-type neutralization kit.





To achieve the highest boiler efficiency in a condensing boiler system, the goal is to utilize the lowest possible hot water temperature to satisfy the load. With this strategy, as the hot water supply temperature decreases, there is a need for larger, heat-transfer surface areas at the heating coils and terminal units. To demonstrate this, the linear footage of radiation is shown in Table 2 as an example of how the amount of heat transfer area increases as the average hot water temperature decreases based on a space heat loss of 5,000 BTU/H.

Table 2: Sample steel radiation heat output per- linear foot based on average water temperature.

Average Hot Water Temperature	180°	170°	160°	150°	140°	130°	120°
Heat Output [BTU/H/LF]	914	812	713	616	523	434	349
Length Required [Feet]	5.5’	6.2’	7.0’	8.1’	9.6’	11.5’	15.2’

For a typical private office that is 10’-0” wide by 15’-0” deep, with the 15’-0” dimension being the exterior wall dimension, it is possible to see the effects the water temperature will have on the radiation selection. Despite the additional length of radiation required as the water temperature decreases, this example shows that there is still sufficient space within the room to accommodate the length of radiation required up to the 120°F average hot water temperature. Also, since it is typical to install the radiation enclosure wall-to-wall for aesthetic purposes, the only extra cost is the additional finned surface area for heating, which is nominal compared to the cost already invested for the wall-to-wall radiation enclosure.

It is important to note that this phenomenon of decreased hot water supply temperature and increased heat transfer surface area exists for all heating coils and terminal units in the system and must be addressed in the design phase to avoid surprises during construction and occupancy. In order to compensate for this, heating coil surface area can be added based on the physical width and length or by adding additional rows to a coil. The specific application will depend on the best approach for overall system efficiency at the lowest first cost. For heating coils in air handling units, additional surface area is typically not a concern as the unit has sufficient space to accommodate additional rows at a minimal increase in air and water pressure drop.

For a VAV box reheat coil, most VAV box coils come standard as one- or two-row coils, which will not provide the required heating capacity at acceptable pressure drops with reduced hot water supply temperatures. The first and most cost-effective option is to maintain the same VAV box and increase the coil depth to a three- or four-row coil, which typically provides the capacity required but at the expense of unacceptable air pressure drops. A second option is to provide a loose coil optimized for size, capacity and installation. With this option, installation costs will increase as additional duct transitions to and from the reheat coil are required. The best approach is to maintain one dimension of the VAV box discharge consistent with the reheat coil dimension to limit the transition required to the coil. A third option is to increase the VAV box by one size, but maintain the same inlet size of the standard VAV box. Although this approach uses a custom VAV box, it provides an appropriately sized inlet duct for airflow measurement while providing a larger heating coil that may be appropriate to satisfy heating capacity requirements with an acceptable air pressure drop.

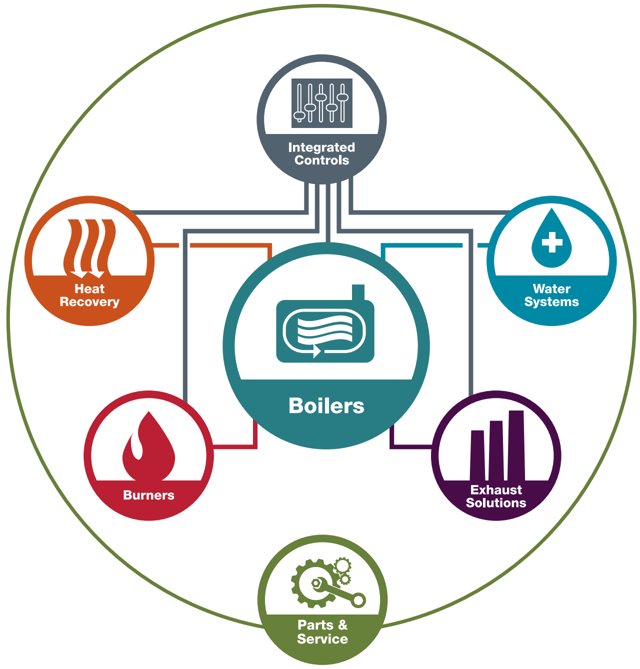
If these recommended options do not work satisfactorily, additional options could be explored. One is limiting the discharge air temperature based on the capacity available from the VAV box with supplemental heat with radiation, or use a fan-powered VAV box to increase the heat capacity available. Table 3 evaluates each of these options based on a total-design cooling flow of 1,000 CFM to demonstrate the various options and relative impact of each.

Table 3: VAV box and reheat coil comparison.

	Standard VAV Box	Standard VAV Box	Standard VAV with Loose Coil	Oversized VAV Box
Box Size	10”	10”	10”	12”
Inlet Size	10”	10”	10”	10”
VAV Box Outlet Size	14” x 12”	14” x 12”	14” x 12”	17” x 14”
Coil Size	14” x 12”	14” x 12”	16” x 12”	17” x 14”
Flow Rate	0.6 GPM	0.6 GPM	0.6 GPM	0.8 GPM
Coil Pressure Air Drop	0.22 IN WG	0.76 IN WG	0.08 IN WG	0.30 IN WG
Coil Pressure Water Drop	1 FT HD	< 1 FT HD	< 1 FT HD	< 1 FT HD
Heating Capacity	13.6 MBH	14.4 MBH	14.0 MBH	13.8 MBH
Number of Rows	1	4	2	3
Hot Water Supply Temperature	180°F	140°F	140°F	140°F

Finally, condensing boilers require system controls to provide minimum system flow to the boilers and/or pumps. This can be accomplished in a couple of ways as discussed in a previous white paper. One method is to use a minimum-flow bypass pipe somewhere in the system with a two-way temperature control valve in the bypass pipe between the hot water supply and return piping. This method requires a flow meter to provide a means to modulate the bypass valve when the minimum flow is not maintained in the system. A second method is to replace a select amount of two-way control valves at the terminal units with three-way control valves. This allows for a constant flow at the three-way control valves and can be used to achieve the required minimum flow without a flow meter.

In summary, there are additional design requirements that must be addressed in the implementation of a condensing boiler system, including items that will impact first cost and operational costs. The use of condensing boilers typically results in a lower first cost due to the reduced number of pumps, valves, and piping (quantity and size) needed. However, careful consideration must be given to venting, condensate disposal, heat transfer surface area, and system controls to ensure the system operates at its highest overall system efficiency.



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