Comparing Medium-mass Boilers to Instantaneous Boilers

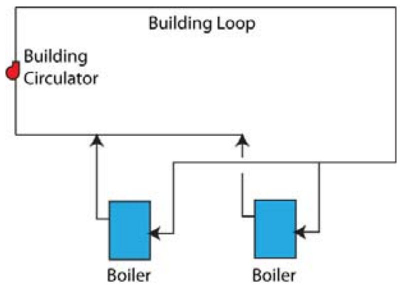
Definitions:

A medium-mass boiler contains between 80 to 160 gallons of water. In a 2 million BTU boiler, the amount of water equates to an input of 12,500 BTU per gallon of stored water.

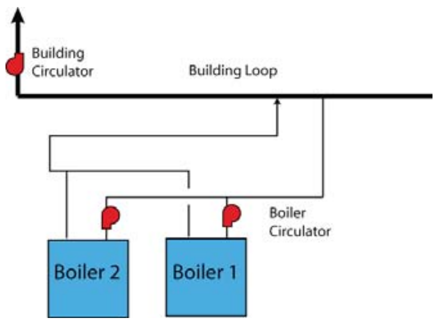
An instantaneous boiler contains very little water. The stainless steel or copper water tubes that comprise the heat exchanger contain around 4 or 5 gallons in a 2 million BTU boiler. This equates to an input of 400,000 BTU per gallon. Because of the extreme input to storage ratio, special considerations are necessary when installing and operating an instantaneous boiler. These considerations are primarily focused on providing a critical amount of water flow through the boiler while it is operating. If water flow through the boiler is too low, excessive temperature can build up in the boiler causing nuisance lockouts.

Boiler Piping:

Medium mass boilers can be piped directly to the building loop as a “primary-only” arrangement using the building circulator to flow water through the boilers. Because medium-mass boilers have a very low (sometimes hardly measurable) pressure drop when water is flowing through them, they ordinarily have no impact on the sizing of the building circulator. This piping arrangement is illustrated below.



Instantaneous boilers require a separate piping loop to isolate flow from the main building loop. This boiler loop, often referred to as a “secondary” loop, requires the piping to each boiler to include a dedicated circulating pump. This arrangement is illustrated below.



In order to provide the correct gallon per minute flow through the instantaneous boilers, several elements of the secondary loop design are critical to proper operation. These are due to the relationship between flow, pressure drop and temperature rise.

1. The piping circuit from the building loop to the boilers must be sized and designed to avoid excessive pressure drop and velocity as water flows through it.

    a. The pipe diameter must be adequate to handle the flow without excessive water velocity. Otherwise the flowing water can erode the pipe, create noise, or both.

    b. The piping circuit must be designed with a limited number of fittings; particularly elbows due to the high pressure drop created. Elaborate and circuitous piping layouts must be avoided.

    c. Piping that is shared by the boilers (common pipe) must be properly upsized to carry the flow of all boilers at the proper velocity and again without excessive pressure drop.

2. The boiler pump must be size to provide the required gpm flow rate for the boiler against the pressure drop created by the boiler and all the piping and valves connecting it to the building loop.

3. It is often recommended that the piping be a reverse return layout in order to more easily balance flow through the boilers.

4. The piping at each boiler must include a check valve in order to avoid short circuiting of water. If only one boiler is firing, its pump will pull water through the non-firing boilers in addition to pulling water from the building loop. Because the boilers are connected to a common hot water outlet pipe, the water drawn through the non-firing boiler is already hot. This hot water re-entering the firing boiler will cause an unwanted temperature rise capable of shutting the boiler off on its high temperature limit prior to the building loop achieving the desired temperature.

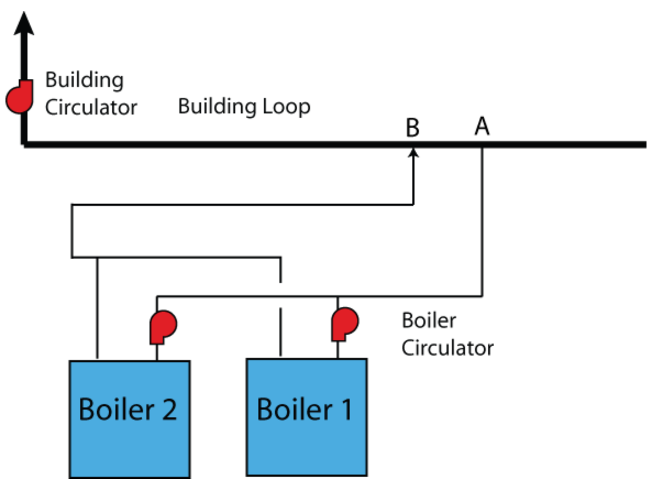
5. Non-condensing instantaneous boilers must not have water colder than 130 degrees entering the boiler. Otherwise, products of combustion will begin to condense on tubes and cause the heat exchanger to fail prematurely. This will also cause corrosion of the vent if it is not designed for condensate accumulation as is the case with negative draft vent materials. This temperature requirement frequently requires a low-temperature bypass loop feeding hot water from the boiler outlet through a thermostatic mixing valve and blending it with water entering the boiler in order to increase its temperature.

    With all that is necessary to design and install the secondary loop for proper operation, it is no surprise that many of these systems require some rework when bringing the instantaneous boilers on line. In addition, the required piping, valves and pumps and the labor to install them increases the cost of installation compared to a medium-mass boiler.

Building Loop Flow:

Many building systems are now designed with measures to vary the flow through the building loop. If a medium-mass boiler is connected to such a building loop, the varying flow through the boiler usually has little effect on boiler operation. However, with instantaneous boilers, changes in building flow can have a profound effect on boiler operation.

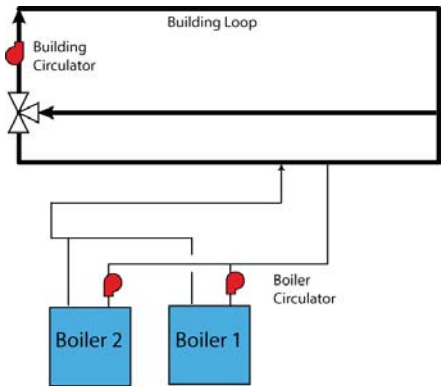
With instantaneous boilers and the required primary-secondary piping, it is recommended that the flow through the building loop be 25% greater than the flow required by the boilers. For example, a typical 2 million BTU non-condensing instantaneous boiler will have a boiler flow rate requirement of about 95 gpm if a 35 degree temperature rise is desired in the boiler. This means that if one boiler is firing, the minimum recommended building flow is 119 gpm. If two boilers are firing the minimum recommended building loop flow becomes 238 gpm; and so on as each additional boiler adds 119 gpm to the building loop flow requirement. As illustrated below, the boilers are designed to pull water from the building loop at point A and inject heated water back into the building loop at point B. If the flow through the building loop is lower than the recommended minimum flow, the boiler pumps create a reverse flow in the building loop causing the heated water at point B to flow backward to point A and return to the boiler. This process is continuous and the water in the boiler reaches a temperature that causes the boiler to shut down due to an over-temperature condition. This shutdown can occur prior to the building loop returning to its desired temperature.



It is fair to say that flow is not always a problem. In applications with constant speed building circulators, the building flow is often greater than the flow required by the boilers. In other cases, the flow through the boilers can be reduced to compensate. This increases the temperature rise in the boiler, but is normally not an issue unless the flow correction is extreme. *(Flow rate is inversely linear to temperature rise in the boiler and temperature drop in the boiler loop. The higher the flow rate, the lower the temperature rise in the boiler or temperature drop through the building loop. The lower the flow rate, the higher the temperature rise in the boiler or drop through the loop.)*

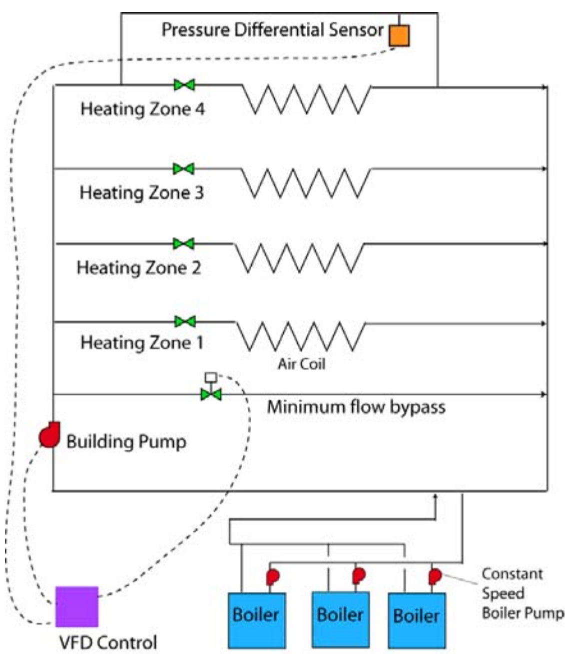
However, this is a much bigger concern in systems designed to alter flow rates.

The illustrations below show examples of variable flow building loop systems.



3-Way Metering Valve System:

This type of system uses a 3-way metering valve to maintain building loop temperature and will vary flow through sections of piping. This configuration is often used with non-condensing boilers that are combined with a building loop temperature reset. It allows the loop temperature to be lower than the required temperature in the boilers, given that non-condensing boilers require a minimum temperature to avoid condensation. The valve opens and closes the "boiler" port as required to maintain loop temperature. When it does, this varies the flow through different piping sections. Although illustrated with instantaneous boilers with primary-secondary piping, this application is not suitable for instantaneous boilers. The changing flow across the section of building loop where the boilers connect will cause temperature control problems with these boilers. Non-condensing, medium mass boilers can however be installed in this type of system.



Variable Frequency Drive System:

This type of system uses 2-way valves on heating zones that can be completely shut off when there is no call for heat in the zone. The building pump uses a variable frequency drive to alter its motor speed, which alters flow rate. As zones shut off, flow rate is reduced because there is less of a need for heating water to be circulated through the building. The ability to reduce motor speed can save $1000s per year in electricity with a 6 million BTU boiler system. This type of VFD system is used with both condensing and non-condensing boilers.

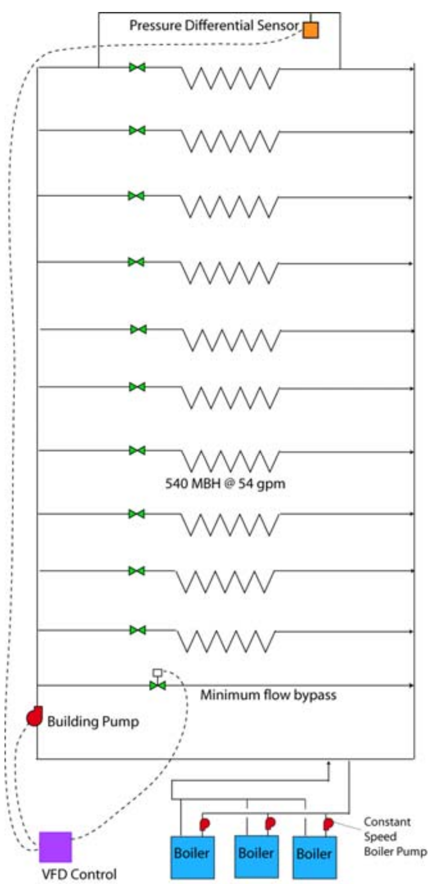
When installing instantaneous boilers into such a system, extreme care must be taken to ensure that the minimum flow through the building loop does not drop below the level required by the boilers. This limits the ability of the variable frequency drive to reduce flow rates, which in turn reduces the financial reward from operating such a system.

Medium-mass boilers can be installed into this type of system without compromise.

More issues with VFD systems and instantaneous boilers

With condensing boiler systems, overall efficiency can be improved if numerous boilers are operating at low firing rates instead of a single boiler operating at a higher firing rate. This method of sequencing many boilers to operate at lower firing rates is called parallel boiler operation. This method energizes additional boilers once the firing rate of the boilers already operating reaches a certain point. For example, if one boiler is firing and reaches 50% of it firing rate, an additional boiler is brought on line so the load is split between them with each boiler firing at 25% of rate. When these two boilers each reach a 50% firing rate, a third boiler is energized and now the load is split evenly between the boilers with all three operating at 33% of rate. If a single boiler where to carry the load at full fire, its efficiency may be 90%, for example. With three boilers firing at 33% of rate, the efficiency of all the boilers may be 93%.

With instantaneous condensing boilers installed in a VFD system, the ability to employ a parallel boiler operating scheme is greatly diminished. This is due to the incompatibility of the building flow rate and the required boiler flow rate. For example, three 2-million Btu instantaneous condensing boilers set up for a maximum temperature rise of 45 degrees in the boilers will have a flow rate requirement of 249 gpm (83 gpm each). The pumps attached to the boilers are constant flow; meaning that even if the boiler is firing at 25% of rate, the flow is still 83 gpm each. For these three boilers to share the load the building loop must have a 25% greater flow or 311 gpm in order to avoid the reverse flow through the boilers as was described previously.



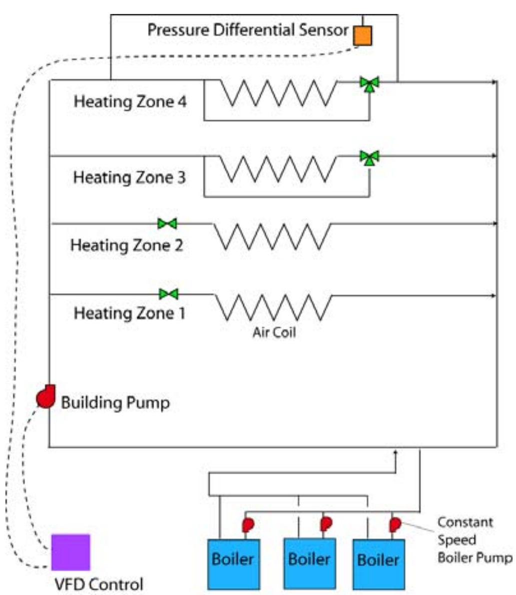
The incompatibility exists because the VFD controlled building circulator is attempting to supply the flow required by the heat emitters in the building and this frequently differs from the minimum building flow required by the boilers. To illustrate, the diagram of a VFD system has been expanded to show a more realistic system with 10 heating zones each rated at 540,000 BTU with a flow requirement of 54 gpm. At maximum capacity, this boiler system requires an output of 5.4 million BTU with a 540 gpm flow. It is recommended that the minimum flow of the building pump only be reduced to 30% of its maximum capacity to ensure longevity of the pump. This is the purpose of the minimum flow bypass loop. The required flow at 30% of the pumps capacity is 162 gpm. As heating zone valves open on a call for heat, additional gpm is required and the VFD reacts by increasing the rotational speed of the pump. As the building flow increases, the valve on the bypass line begins to close as the bypass becomes increasingly unnecessary. In this illustration, once the building heat load becomes 30% of the boiler capacity or roughly 1.62 million BTU with 3 heating zones regularly opening and closing, the bypass is completely shut as the building flow averages 162 gpm, equaling the 162 gpm minimum requirement for the building pump.

If the instantaneous boilers are employing a parallel operation as described, two boilers would be firing at 45% of rate or 810,000 BTU output to meet the building load. However, these two boilers would require the building loop flow to be 207 gpm. At 162 gpm, the building flow is not equal to the minimum requirements of the boilers.

To further illustrate the incompatibility, assume the building heat load increases to 4 zones regularly calling for heat for an average BTU requirement of 2.16 million BTU and a flow of 216 gpm. Under the parallel operating scenario, this would require all three boilers to operating at 40% of rate and requiring a building flow of 311 gpm. Again, the flow required by the building heat emitters does not equal the flow required by the boilers.

There are ways to compensate for this. In this example, the amount of load carried by the first boiler before energizing an additional boiler to share the load would equal almost 100% firing rate. The two boilers would then share the load at 50% of rate. This is risky though, because if the load drops only slightly, the building flow rate once again is inadequate for two boilers. The best way to address this situation with boiler control is to abandon the parallel operation altogether and operate the boilers sequentially; that is boiler 1 achieves 100% of rate and remains there as boiler 2 is energized and fired at a rate sufficient to meet the load. This compromises the increased efficiency of numerous boilers operating at low firing rates but retains the efficiency gain of the variable speed pumping system.

Another way to compensate is to leave the building bypass open until the building load reaches about 60% of the boiler system capacity. This would provide adequate flow for the three instantaneous boilers at all times. However, it largely defeats the purpose of installing the variable speed building pump system by requiring addition electrical consumption of the building pump only to satisfy the boiler flow requirements. This is especially troublesome because for the majority of the heating season, building heat load will be at or below 60% of the boiler system capacity.



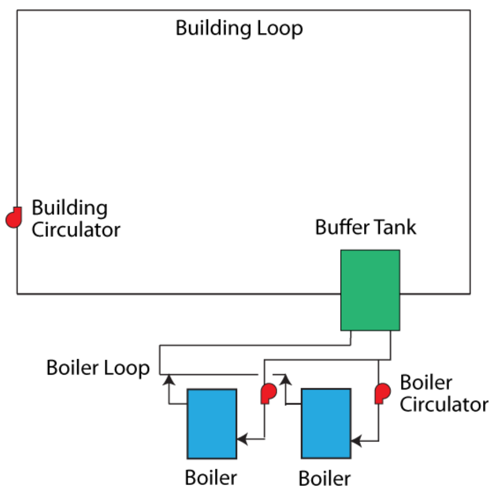
Alternately, the VFD system can be designed as illustrated here. On some of the zones, the 2-way valves can be replaced with 3-way valves, thereby ensuring that there is always adequate flow through the building to satisfy the minimum flow requirements of the boilers. But again, this largely defeats the purpose of installing the VFD drive on the building pump because water flow through the building exceeds the flow required by the heat emitters for much of the heating season. The financial reward of installing the VFD is reduced.

Because medium-mass boilers do not have critical internal or building flow rate requirements, they can be installed in VFD building systems without compromising the operation of the VFD or the boilers.

Load Matching and the Requirement for Additional Storage

Because instantaneous boilers contain very little stored water, their ability to match the building load to boiler output can be achieved only by modulating the burner. In an instantaneous boiler, there are installations where modulating the burner down to 20% of rate still overpowers the heat requirement of the building and results in short cycling the burner. Short cycling occurs when the heat demand of the building is met in a matter of minutes by the boiler causing the boiler to shut off only to call for heat again a few minutes later as the heat is rejected from the boiler loop into the building. This occurs only during very mild temperatures when building heat loss is minimal. It can however shorten the life of boiler components.

To compensate for the instantaneous boiler's occasional inability to meet a low building heat load without cycling, these boilers are sometimes installed with buffer tanks. The size of the tank is determined by a formula primarily designed to accommodate a minimum length of firing cycle. Depending upon a number of factors, the buffer tank can be up to 500 gallons. The tank is installed as illustrated below.



These tanks are ASME code, section VIII vessels and can add $3000 to $6000 to the required upfront equipment cost of the boiler system depending upon their size, plus installation cost. In addition, the boilers must still be piped primary-secondary.

Medium-mass boilers, because they contain a volume of water that acts as a built-in buffer tank, do not experience similar short-cycling during low demand periods. No additional storage is necessary.

Operating Cost – Additional Electrical Consumption

The dedicated boiler circulating pumps required by instantaneous boilers add to the annual electrical costs of the building. On a single 2-million BTU instantaneous boiler, for example, the cost of operating the pump can easily be $500 annually in a typical heating season.

Medium-mass boilers piped primary-only do not require boiler pumps.