Boiler Optimization Series: Right-sizing Your Boiler Plant

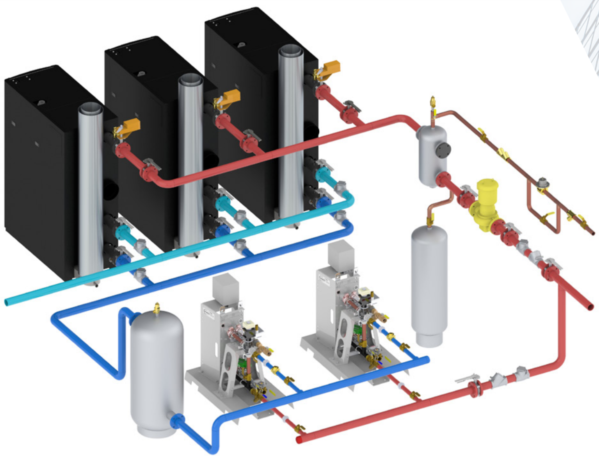
Andrew Macaluso, Strategic Accounts Manager
Theresa D'Amore, Manager, Systems Engineering

AERCO
A WATTS Brand

Boiler Optimization Series: Right-Sizing Your Plant

When designing a new or replacement boiler plant, there are a range of key design factors to consider. The physical layout of the plant must be designed to fit in the space allotted yet provide sufficient room for maintenance technicians to effectively do their work. The piping, controls, and support equipment design should be focused around efficient operation for reduced fuel and maintenance costs. It is critical to correctly size equipment to prevent excessive cycling for a long operational lifespan.

Initial Design Selections



For a given design-day heating load, the first choice to make is how many units of which input range to use. A good goal is to aim for a total of 3-5 heat exchangers. For commercial buildings, this may be three separate pieces of equipment. For smaller, light-commercial buildings, this may be a single boiler with several internal heat exchangers operating as a single unit.

At first glance, a single large boiler may seem to offer the best dollar per BTU value. While this was common of older mechanical plants run by either large built-in-place cast iron or Scotch-Marine boilers, there is a significant weakness in this type of system that cannot be ignored. When a unit is brought offline, either for reactive service or preventive maintenance, the building will be completely without a heat source. For this reason, modern boiler plants typically consist of multiple smaller units.

When designing for redundancy, it is very common to provide an N+1 system. This style system is meant to provide full plant capacity in the event that one boiler is brought offline. For these reasons, an ideal boiler plant would provide a minimum of two units to cover the heating load, and a third unit for N+1 redundancy. Adding a third boiler at 50% of the plant capacity (for 2+1 plant design) will sometimes mean purchasing a rather large boiler for only intermittent use. To reduce the size of the "redundant" boiler, a 3+1 or 4+1 plant can also be installed. In these cases, the redundant boiler will be 33% or 25% of the design load and may reduce the initial equipment costs while still maintaining plant capacity and redundancy. Using different equipment sizes can also be effective: for example selecting 2 units capable of meeting the peak design day load and a third at half the capacity of the main equipment. This method provides effective redundant capacity for the majority of a heating season, increases the overall plant efficiency, and can reduce cycling during the shoulder months by more closely matching the building heating demand.

There is a diminishing return to increasing the number of units in a plant due to the increasing maintenance costs and larger space requirements. It may seem advantageous to split the design among many boilers. A plant with 3+1 design will require a "redundant" unit at 33% of the plant capacity, but a plant with 6+1 design will only require a redundant unit at 17% of the total plant capacity. The drawback is that the maintenance cost of operating seven units is much higher than that of four units. This includes both the material costs of consumable items like gaskets, as well as the labor cost for maintaining a higher number of units.

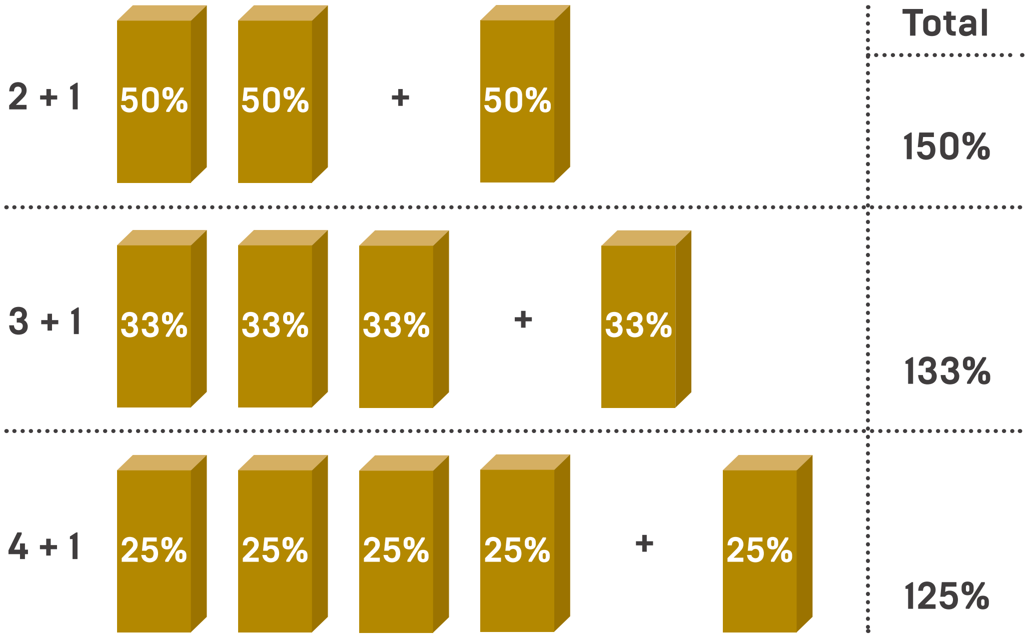


Figure 1

Another solution that is gaining popularity is to use a “modular” style boiler to increase the plant redundancy. The term “modular” is used in several different ways. This has been used to describe several individual boilers controlled as a single system, as compared to a single large-mass boiler. It has also been used to describe field-assembled units that combine into a single unified system. Most commonly, this is used to refer to a single pre-packaged unit that has multiple internal heat exchangers, each with its own dedicated burner and gas train. These style modular boilers provide a complete boiler plant in a single enclosure with one set of gas, water and flue connections. The term “sectional” boiler may also be used, but it is important to differentiate between a boiler with single burner built of assembled cast sections and a boiler than offers the internal redundancy of multiple burners.

The appeal of a modular boiler is that each unit has the redundancy of a multiple-boiler plant. Designing these plants has the same considerations as larger plants; a target of 3-5 total heat exchangers is considered ideal. If a boiler has four internal heat exchangers and the plant is designed with a total of three boilers, that is a total of 12 heat exchangers that must be serviced and maintained. Modular boilers are best applied in light-commercial applications that may only have the available footprint for one or two units. When installing only one modular unit it is very important to understand that the unit will need to be powered down for maintenance and other work; critical facilities should always install a redundant unit to ensure an uninterrupted supply of heat.

For example, a 750 MBH heating plant could easily be served with a single modular boiler consisting of four 250 MBH modules (for a single 1000 MBH boiler). This would provide 3+1 design with low maintenance costs in a very compact footprint. While the same unit might be applied in a 4000 MBH heating plant, this would create a significant increase in maintenance costs while not reducing the footprint. A 4000 MBH plant would require a minimum of four standalone 1000 MBH modular boilers, for a total of 16 heat exchangers. This means every planned maintenance would require 16 sets of gaskets, 16 combustion calibration procedures, and so forth. In this case, using either (3) 2000 MBH boiler (5) 1000 MBH boilers would be a more appropriate design to minimize both initial equipment costs and maintenance considerations.

After the equipment selection has been made, designers should immediately review requirements such as piping, venting and controls necessary to operate the units as intended. Considering these items up front will save a project from schedule over runs and costly change orders. A common mistake is to overlook exhaust and supply air needs until the equipment arrives for install, at which point there may be no way to safely route the exhaust leading to cost and schedule overruns. Venting in particular deserves a close review, as venting requirements vary greatly even between similar styles of equipment. Some manufacturers will allow units to be common vented. A boiler plant that can use common manifolded venting may be more practical than multiple individual vents. Look for more on this topic in our upcoming article this Fall.

Initial Installation and Footprint Considerations

Once the boilers have been sized and the number of units agreed upon, they must be laid out in the mechanical room. The advantages to having a small footprint are obvious, but the drawbacks are less-so. When laying out the mechanical room, be careful not to gain floor space by sacrificing serviceability!

Footprint is a tradeoff between tight installations and serviceability, and both must be considered. While it may look nice on a drawing to have units with only a few inches of space in between, a technician will not be able to work in between the units to service anything on that side of the unit. When the space is available, it is always advisable to provide as much space as reasonably possible between units, as well as away from walls, support beams and other structures. When these spaces are not available, many manufacturers will allow some sort of “zero-side clearance” wherein a boiler is placed directly next to a wall or adjacent boiler. Each manufacturer has its own rules regarding zero-side clearance, but a good rule of thumb is to only use zero-side clearance on a single side of the boiler and keep the other side available for ease of service. Generally speaking, this means leaving one boiler width empty for the worst case scenario of an entire boiler removal. For instance, if there are two boilers of width 24” and a side-by-side space of 8’, it would be better to pair the units together with zero-side clearance and 24” in between than to spread 16” equally. See figure 2 below.

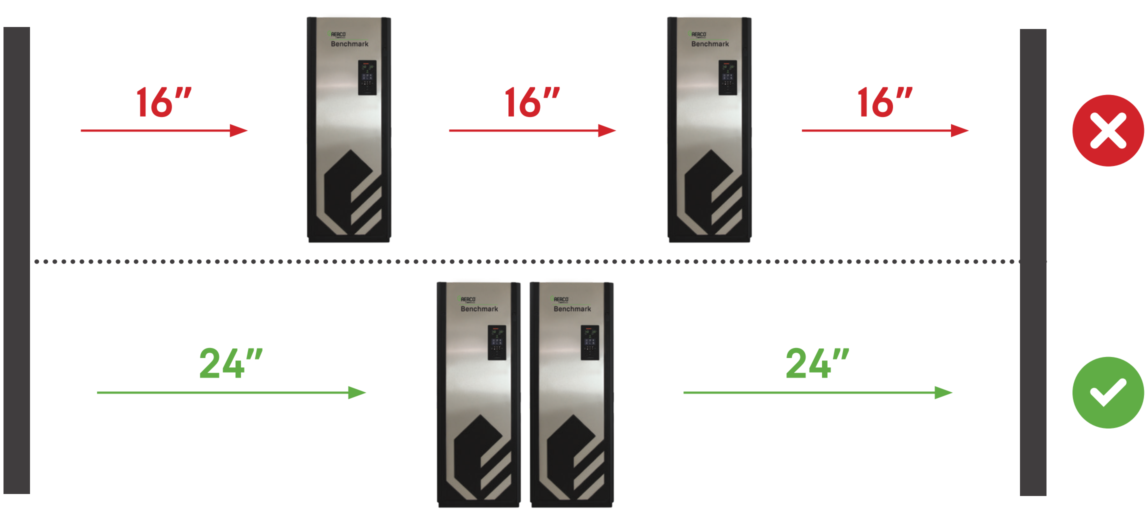


Figure 2

Similarly, overhead clearances must be understood and respected. This can be difficult to sustain as the mechanical room is outfitted. Once the boilers are in place, ducting, gas and water piping, electrical conduit, and communications cables must all be run. This does not include other equipment in the mechanical room that may be installed such as overhead heaters. It is important to understand exactly what the equipment’s overhead clearance is needed for and how much open

space must be provided. Will the unit be serviced exclusively from the front, or will some parts be removed from above? Is there sufficient room for a technician to operate? These considerations may require the boiler's maintenance instructions or the expertise of the manufacturer's rep.
In retrofit and renovation projects this is critically important. NFPA 54 discusses where and how to bring combustion air into and combustion exhaust out of a facility, in retrofit or renovation projects understanding these and the boiler manufactures requirements can prevent eleventh hour redesigns. The best placement of heating equipment may be determined by fire protection code requirements rather than the most convenient floor space in a mechanical room.

Another significant factor that is often overlooked is how the boilers will be maneuvered into place. For new construction there are many options, as the boilers can be placed before walls or ceilings are installed. For retrofits, however, this can be a significant hurdle to clear. If equipment cannot fit through existing hallways and doors, a wall may need to be demolished and rebuilt, or a ceiling opened up and later repaired. For penthouse installations, if the boiler cannot fit in an elevator, or is too large to be rigged up a staircase, this may require renting a construction crane. Cranes also typically require street permits, partially or completely stopping traffic for a day, and police escort. All of these rental, demolition, and repair costs can add up to more than the cost of the boilers themselves. It is important to look beyond the initial cost of equipment and consider the complete installation costs. Even in new construction when units can be installed with existing construction cranes and before roofs are in place, consider potential delays to the project if equipment is not delivered on time. Similar to the high costs of retrofitting boilers with overly large footprints, the costs of construction delays add up rapidly for every single day one aspect of construction is delayed. The costs of these are often overlooked when selecting equipment, leading to perceived "low cost" units costing more than a premium boiler with smaller footprint.

Ensure Condensing Will Occur

When reviewing existing systems, it is important to note what is feasible to change. The opportunity exists to completely overhaul a system, but does the budget? Fortunately, there are some small, and not so small, changes that can have a big impact. There are options where changes to existing piping, pumping, or controls mean the difference between costly or cost-effective operation.

- As discussed in a previous article, temperature reset will always result in better equipment efficiency and therefore lower fuel costs. This applies to Outdoor or Seasonal Resets as well as Night and Weekend Setback schedules. In all cases reducing heating water delivery temperatures increases the opportunity to condense flue gases which leads to direct fuel saving.

- Tuning the system supply temperature is also a very effective method of reducing cost without impacting occupant comfort. Facility personnel can drop the heating water supply temperature during peak heating season until occupants notice the change, at which point they can increase the temperature one or two degrees to a point that was not affecting occupant comfort. If an outdoor reset schedule is in place it may also be revised based on occupant feedback.

- Slowing down water flow in conjunction with a lower temperature supply is also effective and saves on pump energy as well as fuel cost. As the flow rate is inversely related to the ΔT, lowering the flow rate will lower the return water temperature and thus increase efficiency.

- A more labor intensive change to the piping layout can also payoff. If an existing system utilizes primary-only piping and building demand is upward of 1MMBH, converting to a primary only arrangement will save significantly on operating costs as there are fewer points of failure and greater opportunities to condense flue gasses. It is important to note that water tube heat exchangers should only be installed in a primary-secondary system to protect the heat exchanger from ΔTs greater than their design allows.

These methods can be effective on their own or together on renovation and new buildings alike.

The Importance of Turndown

A key factor in reducing energy costs and unscheduled maintenance and increasing the lifespan of mechanical equipment is the prevention of excessive cycling. The act of turning a boiler on, purging the combustion chamber, and igniting the burner consumes energy. If a boiler cannot fire at a low enough input to support the lowest heating load required, it will cycle on and off to maintain this load. When taken into account, these cycles can significantly reduce the overall efficiency of the heating system. Additionally, every start-stop cycle of a moving component increases the wear on that component. Systems that cycle excessively will see premature failure of moving components like valves, solenoids, and combustion blowers.

The easiest way to prevent cycling is to select equipment with a sufficient turndown ratio. Turndown is the ratio between the maximum and minimum input a boiler can achieve. When installing multiple boilers, the turndown is "added" among the boilers, as the input can range from all units on at maximum fire down to a single unit on at minimum fire. For example, a 2000 MBH input boiler with a minimum firing rate of 100 MBH has a 20:1 turndown. A boiler plant consisting of three of these units has a total turndown of 60:1.

Ideally, a boiler plant will be able to support the minimum heating system requirements with a single boiler at minimum fire. Past this minimum firing rate, increasing the plant turndown has a diminishing benefit. Take as an example a building with 4000 MBH maximum heating load, with an expected 200 MBH minimum heating load and 2+1 design. Using a boiler with only 5:1 turndown will result in a plant that is 15:1, but with a minimum firing rate of 400 MBH that will need to cycle during periods of lower loads. Selecting a boiler with 20:1 turndown instead provides 60:1 overall plant turndown and the ability to match any required heat input without cycling with a minimum plant input of 100 MBH. Increasing each unit to a 25:1 turndown boiler will bring the overall turndown up to 75:1 and the minimum input down to 80 MBH, but will have exactly the same ability to match loads as the 60:1 plant.

The other reason turndown is a crucial factor in selecting equipment is that boiler plants are designed for the coldest days of the year, but will spend most of the heating season operating at significantly less than that design condition. The coldest day of the year for a given location is called the "design day" and is based on ASHRAE bin data. These design days will generally account for <1% of the total runtime on the boilers. Most of the time (>50%) the boiler plant will be operating at a significantly reduced input during the shoulder months. Since condensing boilers are more efficient at lower firing rates, having a high turndown will translate directly to fuel savings.

The Boiler Mass Myth

The other method of preventing excessive cycling is to add water volume to the system. This is a more common solution in residential systems where the system volume is low and single boilers provide a limit to the turndown available. In commercial systems, there is usually sufficient water volume and plant turndown to eliminate the need for a hydronic buffer tank. The minimum system volume in a heating plant is determined by the following equation

$$\text{Min. Volume [gal]} = \frac{\text{Min. Cycle Time [mins]} * (\text{Min. Boiler Input [MBH]} - \text{Min. System Load [MBH]})}{\text{Temperature Rise [}^{\circ}\text{F]} * 500}$$

There is a misconception that cycling can also be prevented by using a high-mass condensing boiler. There is no ASME classification that defines high-mass, mid-mass, or low-mass boilers. It is a terminology adapted by individual manufacturers to describe their product compared to other boiler types. Typically, non-condensing boilers with Scotch-Marine or cast iron designs are considered high-mass when compared to boilers with “low-mass” stainless steel, copper, or aluminum heat exchangers. Some designs, such as larger condensing stainless steel boilers or condensing cast-iron boilers, may be described as “mid-mass” simply as a hybrid between the styles of boiler. Ultimately, what defines the need for a buffer tank is the thermal mass present in the heating system (including the boiler), minimum system load, minimum boiler cycle time, and the boiler plant turndown. Boiler mass is not included in the equation above. The only impact the mass of the boiler will have is in the manufacturer’s recommended minimum cycle time.

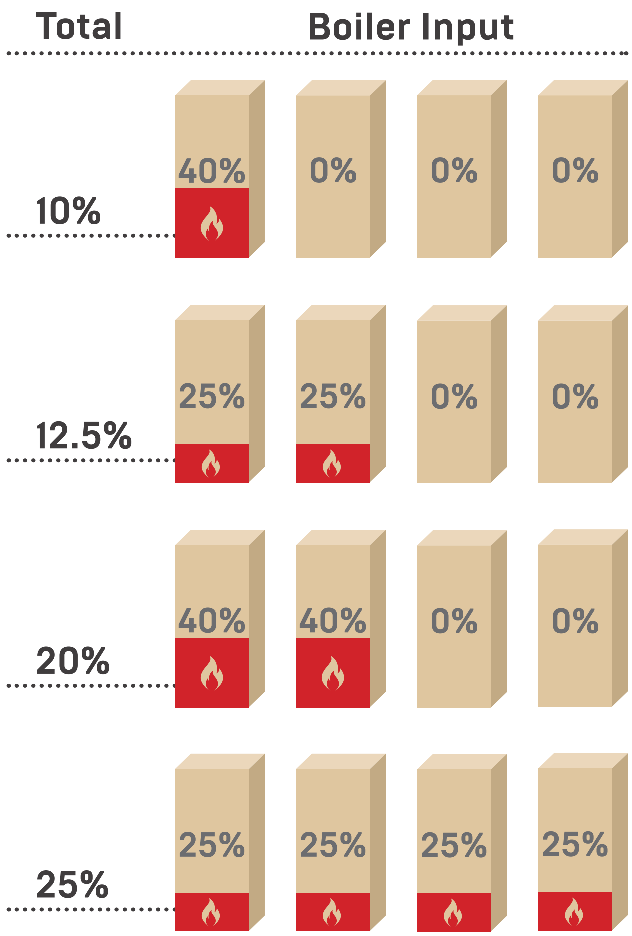
Plant Operation: Sequencing and Lead Boilers

The way a boiler plant is sequenced and modulates firing rate can have a significant impact on operational costs and system longevity. Upon call for heat, a single boiler will begin to fire. This is typically known as the “lead” boiler, and the last unit on is the “lag” boiler. In a multiple boiler plant, the lead boiler should rotate throughout the heating season to balance both the total run hours on each unit and the number of cycles on each unit. If this does not occur and one of the boilers remains the lead throughout the heating season, the components will need to be replaced much earlier than on other units. This means more unscheduled service calls and component replacements. It will also make it difficult to plan end-of-life replacements, as one boiler may be overdue for replacements while others will have relatively little run time and may not need replacement. Most on-board or third-party boiler controllers will perform this lead-lag boiler rotation automatically, but it is important to check for this feature before selecting equipment. This may also be an opportunity to retrofit newer controls on existing boilers to help balance out wear on existing units.

The logic that controls multiple boiler modulation can have a significant impact on system energy use, and may differ from equipment to equipment and system to system. Generally speaking, high-mass boilers like cast iron or Scotch Marine style boilers will be more efficient at full fire than at part load. This is because the radiated thermal losses to the environment are so high with these types of units that at lower firing rates the jacket losses will make a significantly higher proportion of the heat output. This is typically felt in boiler rooms that seem very hot compared to other rooms in the building. For this reason, older systems would bring a single boiler up to full firing rate before bringing on a second unit.

Conversely, most condensing and mid- or low-mass boilers have very low jacket losses. It is not uncommon to see jacket losses in condensing equipment <1% and even <0.1%. Since the heat exchanger surface area is fixed, lower firing rates means better heat transfer into the heating loop and thus higher efficiencies at lower firing rates. Because of this, these systems are typically operated to maintain as many units on at as low of a firing rate as possible without causing undue cycling. In an example plant consisting of three 2000 MBH boilers that can fire down to 100 MBH, a single unit will fire until the load is high enough to split between two units. This may be 400 MBH on a single unit before splitting to 200-200. Units should not split at 100-100 because if the load suddenly decreases the second unit may continually cycle on and off.

Figure 3



Putting It All Together

There are several key equipment features that, if selected properly, will allow your heating plant to operate efficiently and reliably for many years. An ideal boiler plant will have enough heat exchangers to provide reliable operation and sufficient system redundancy, without adding excess maintenance costs. The boilers should be selected with an eye towards ease of installation and footprint, and with high enough turndown to prevent cycling during low loads. Boiler controls must be able to rotate lead boilers and sequence multiple boilers for optimal plant efficiency. By balancing all of these factors, an efficient plant can be designed to maximize heating efficiencies while reducing maintenance and installation costs.

AERCO's advanced, compact commercial condensing boilers and water heaters provide safe, reliable heat and hot water to a variety of markets including education, hospitality, healthcare, government, office buildings, industrial, multifamily housing and more. Our system-design approach enables us to provide customer-specific solutions that deliver superior building performance at a lower operating cost while ensuring uptime reliability.

70 years ago, AERCO introduced an innovative design for an indirect-fired water heater – and it revolutionized the water heating industry. AERCO continued to innovate introducing the first condensing and fully modulating boiler and water heater to the commercial market. Research and innovation continue to be at the heart of everything we do. Learn more at aerco.com.

AERCO®
A WATTS Brand

Heating and Hot Water Solutions

AERCO International, Inc. • 100 Oritani Drive • Blauvelt, NY 10913
USA: T: (845) 580-8000 • Toll Free: (800) 526-0288 • AERCO.com