Modular Boiler Systems for Laboratory Facilities

1 Summary

Energy savings can be realized in the production of heating hot water by modularizing the boiler system[1]. Equipment in modular, or multiple, boiler systems (MBS) are designed to operate singly or together to meet heating hot water loads. Overall benefits include:

- Right-sizes boiler capacity to match variable load
- Provides redundancy to improve boiler maintenance and replacement
- Increases flexibility for upgrading or expanding boiler capacity
- Eliminates standby energy waste

2 Laboratory Benefits

A MBS contributes to optimizing energy efficiency and increased safety in a laboratory facility in a variety of ways[1]:

2.1 Matches variable load

Modular boiler systems maximize system part-load efficiency. Part-load operation is caused by a laboratory's heating and cooling diversity from fume hood operations, process loads, climate, and occupancy. Multiple boilers allow staged operation to match a laboratory's varying heating load.

An MBS with multiple, *modulating* boilers has an even greater ability to match a varying heating hot water load. A boiler with a simple on-off firing burner has a turn-down ratio of 1-to-1, while a modulating boiler has a fire-rate with an adjustable range of output capacity. Therefore, using multiple modulating boilers increases an MBS's ability to match a varying load by improving its *overall* turn-down ratio. For example, when modulating boilers, with a "stable" firing rate of 20 percent of their full output rating, are used in an MBS, a five-boiler system can easily provide a turn-down ratio of 25-to-1, rather than a 5-to-1 ratio of a system with simple on-off boilers.

2.2 Provides Redundancy

MBSs have an intrinsic benefit of boiler redundancy. The system's multiple units result in spare capacity that is readily available to provide back-up for a failed boiler. Additionally, replacement is simplified because any one boiler can be easily taken out of service without disrupting the hot water heating supply to the laboratory.

2.3 Increases Flexibility

Modularized systems more easily accommodate changes of laboratory mission. If laboratory heating loads are increased, then additional boilers can be added to existing systems, especially when provisions are made for expansion in the lab's original system design. Upgrades to newer, more efficient units can be implemented.

2.4 Eliminates Standby Losses

Modular boilers allow cold-starts that do not require continuous operation. Due to safety concerns and research criticality, many laboratories maintain heating systems with backup boilers in a "hot" standby mode ready to assume the heating load within a moment's need. These boilers waste energy due to energy losses by convection through their stacks and by radiation through their insulating "jackets." Therefore, energy savings from a modular boiler system are realized by eliminating hot, idle boilers. These savings range from 40 to 60 percent compared to conventional boiler systems.

3 Case Study LBNL B70 Laboratory

In 1992, a simple energy-use study was completed of an older boiler system installation in Lawrence Berkeley National Laboratory's (LBNL's) Energy, Environment, and Nuclear Science Laboratory (B70). This study indicated that a significant amount of B70's original boiler-system's energy was being wasted in through a variety of standby losses including: air convection, up boiler stacks; radiant, through jacket insulation; water convection, through boiler hot water tanks. Consequently, a more thorough, detailed analysis was performed to more carefully estimate potential energy savings. Completed in 1993, this analysis provided justification to implement a retrofit project to install LBNL's first modular boiler system. Right-sizing the MBS became an immediate design issue.

3.1 Original Conditions

The existing boiler system for Building 70 included two *Husky Ray* forced draft, natural gas fire-tube type boilers rated 4,200,000 BTUH input and 2,340,000 BTUH output. Both boilers were equipped with *Ray Power* burners and two-stage firing controls. These two boilers were installed in January, 1965. At the time of the retrofit, they were twenty-seven years old, with a nominal useful life of thirty years.

The boilers were operated on a lead/lag basis, and both were constantly enabled with fixed set points. There were no automatic isolation valves to isolate the standby boilers. Automatic start of the boilers from a cold standby condition was not recommended and would be detrimental to the boilers. Therefore, both boilers were kept in a "hot condition", either as the primary operating boiler (lead boiler) or as a hot standby boiler (lag boiler). A summary of the B70 boiler and heating-water characteristics that significantly impacted fuel/energy efficiency follows:

- Physical size and oversized capacity of the boilers, which directly impacts radiant and convective, stack heat-loss rates.
- Firing operation cycles, which include boiler-purge cycles, that waste internal heat from the boilers every time they cycle off and on,
- Step-firing sequences that require on/off cycling to match heat input to load, as opposed to a more efficient modulating input to achieve steady firing at a rate that matches load.
- Constant-flow, parallel heating water piping configuration, which split the heating water flow through the two parallel boilers, further contributing to the cyclic-firing characteristic.
- Constant boiler temperature operation, with no temperature reset during mild weather, which maintained boiler parasitic losses at a relatively constant level, regardless of heating load.
- Boiler's physical inability to tolerate startup from cold standby, which requires that the spare boiler be maintained at, or near, operating temperature for immediate availability in the event of a lead-boiler failure.

3.2 Estimating Energy Savings

Today, most laboratory HVAC designs provide an uncertain amount of reheating of mechanically cooled air for spaces that do not require the "coldest" airflow; so-called *simultaneous* heating- and-cooling. This design approach presents a major energy-savings opportunity and analysis methods that include evaluating reheat should be used. See the Labs21 Best Practice Guide: Minimizing Reheat Energy Use in Laboratories for additional information.

However in the case of B70, no mechanical cooling is provided. This greatly simplified estimating the energy waste of this lab's boiler system to a matter of determining boiler standby and conversion losses. A linear regression analysis[2] was used, with heating degree-days per month as the independent variable and CCF (100s of cubic feet of natural gas) per building as the dependent variable, to determine the constant, standby element of gas usage for B70. The regression's ***"m"*** coefficient, conversely, indicates the magnitude of the actual heating load, including conversion inefficiencies, as a function of heating degree-days.

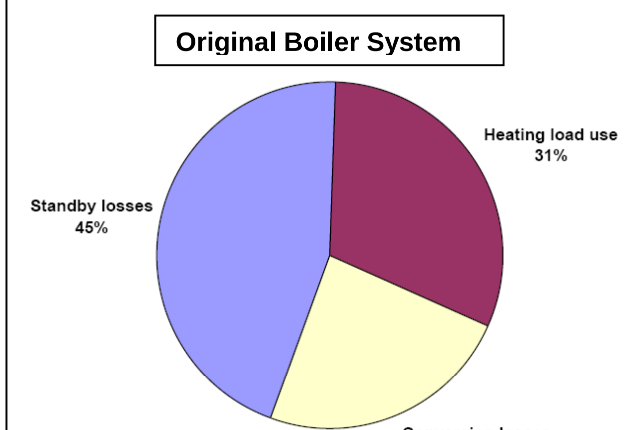

Figure 1

The net impact of the original boiler system's characteristics, noted above, was that natural gas usage was disproportionately weighted toward standby losses. The regression analysis indicated that nearly half of the natural gas consumed was to idle, standby losses with slightly less than one-third of the total fuel used actually satisfied the heating load, see Figure 1.

3.3 Modular Boiler System Retrofit

At the time of the retrofit, a few retrofit construction issues were eventually overcome including:

- Decommissioning and removing existing boilers
- Right-sizing the new MBS; how many needed?
- Choosing a boiler type; pulse, full condensing
- Planning flue stack layouts
- Arranging pumps and piping
- Resolving controls and sequencing complexities

Decommissioning and removing existing boilers

An appropriate period during the year was chosen for decommissioning and removing existing boiler when heating loads would be at a minimum. Therefore, the retrofit MBS project was completed during the summer.

Right-sizing the Boiler System

The retrofit project interconnected two existing heating systems (one in Building 70 and the other in 70A) and consolidated the two existing systems into one new heating system to reduce boiler standby losses and improve operating efficiency. As noted above, the B70 MBS was intended to be a "satellite" system for two lab facilities. Accordingly, a simplistic evaluation of the combined loads indicated that 18 one-million BTUH (input) boilers would be required. The firm promoting this MBS size was unwilling to more closely right-size the system. Therefore, a "second opinion" was sought by LBNL from an energy-efficiency expert that after analysis recommended 8 to 9 one-million BTUH (input) boilers to satisfy the loads. A compromise was reached with the design firm to arrange the MBS with 11 one-million BTUH (input) boilers. Over the ten-plus years of operating the system, no more than 8 boilers have been fired at once. The maintenance department has found great comfort in having 3 spare boilers, even on the coldest days.

LBNL B70 Modular Boilers

LBNL B70 Modular Boiler Flues

Choosing a boiler type

Many variables influence choosing the best boiler type for an MBS. Choosing full-condensing boilers will result in high thermal efficiencies, but hot water distribution coils and system components must be compatible with these boilers. In a retrofit situation, these components are unlikely to be well-matched to a full-condensing MBS. Full-modulating boilers provide increased turn-down ratios with high part-load efficiencies; however, no modulating boilers were available at the time of LBNL's MBS project.

Planning flue stack layout

One goal of the B70 MBS retrofit project was to re-use the existing vertical stack riser through the building. Due to reduced volumetric boiler exhaust flows, a careful engineering review of convection "draw" of the existing stack was completed. As a result, a smaller, consolidated stack for the MBS was routed within the original stack. The height of the new consolidated stack induced a significant convective draw. Consequently, each individual boiler's stack (before being combined) included a counterbalanced, bypass damper that allowed convection up the main consolidated stack without moving air through each modular boiler. Not moving air through each modular boiler eliminated burner-firing problems and reduced energy loss from the boiler's water jacket.

Pump and Piping Considerations

In the 1993 MBS design for B70, each on-off boiler is manifolded in a primary circulation loop with isolation valves to prevent circulation during inoperative periods. The laboratory load is on the secondary loop and, in special instances, a tertiary loop. Today, energy efficiency of a piping and pump configuration may be improved by using an "all-variable-speed" arrangement in conjunction with full modulating boilers in the MBS.

Control Complexities

In an on/off modular boiler system, a DDC (direct digital control) system compares the system's return water temperature set-point and enables "another" boiler to maintain the set point. As the set point is exceeded by a pre-determined amount, the "last" boiler fired is turned off. Though better that the original system, this level of matching the lab's load can be improved when modulating boilers are installed. Over- and under-shooting the return water temperature set-point will occur and a commitment to an ongoing commissioning of the MBS is necessary to minimize this situation.

An MBS with modulating boilers usually operates with a control strategy that fires an additional boiler rather than apply the maximum capacity of any single boiler. Using this strategy means that when an operating boiler reaches a predetermined high percentage of its maximum output capacity, the next boiler in the system is fired and then two boilers modulate, at the same percentage capacity, to satisfy the load. Two boilers operating lower capacity outputs are more efficient. This in part due to an effectively larger combined heat exchanger surface area that is providing heating water at a lower boiler capacity[3]. When a third boiler (and beyond) is necessary to satisfy the load, either the last two boilers can modulate together or the entire system can modulate in unison.

Another consideration is how to sequence the boilers in the MBS. A so-called "first-on/last-off" sequence always starts with the same boiler as the "lead." In this sequence the last boiler fired is the first one to go off[4]. A modification to this sequence, for instance, may change the lead boiler every week or every month. In this way, a facilities department can conduct maintenance one the prior week's (or month's) lead boiler to ensure the reliability of the entire system. A so-called first-on/first-off sequence cycles through the entire system with each new call for heating hot water. This approach will more or less "uniformly" operate and wear each boiler in the MBS and continuously prove each unit's capability to provide heating hot water.

Modular Boiler installation: Courtesy of Weil McLain

4 Conclusion

For LBNL's first MBS in B70, the standby losses of over 49,000 Therms per year were eliminated and the boiler conversion efficiency improvement reduced natural gas use by an additional 17,000 Therms per year for a total of over 66,000 Therms per year.

MBSs have proven their ability to save energy and increase operational reliability in a wide spectrum of building types for many years. Use in laboratory facilities is especially appropriate due to highly variable loads, heating-capacity redundancy requirements, future flexibility needs, and energy-use reductions.

5 References

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6 Acknowledgements

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