Retrofit or Replace Boilers?

Returning Wealth to the Business

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With the current economic situation causing stress on every front from the crisis on Wall Street to the falling housing market to the failing auto industry, we in the energy conversion industry (including anybody who operates a boiler for heating or process) are also facing some tough economic times, and energy consumption is at the heart of much of it.

Looking at Industrial and Commercial boilers in the United States, we find approximately 400,000 units consuming about 33 quadrillion Btu's per year; 25% of the world's energy. We are importing about 40% of this energy from unpredictable sources and over 60% of these boilers are over 20 years old with operating efficiencies of 70 to 75 %. This not only means we are wasting large amounts of fuel from precarious sources (400,000,000 barrels of oil per year based on 10% waste), but at the same time, fouling our environment with noxious pollutants which adversely impact our health while warming the globe, altering climate and the ecosystem at large. Remember, if we burn less, we pollute less.

So we are in a tough situation with pressures from the environment and pressures to reduce cost to remain competitively viable in a highly competitive global economy. It is impacting our process industries, manufacturing, our hospitals, our schools, our commercial buildings and our government institutions. Energy conservation is a key to remaining viable in today's business environment.

ENERGY IS WEALTH

If we direct our attention to the approximately 400,000 boilers in the United States, and concentrate for a moment on the large Commercial and Industrial sectors only, this would equate to about 160,000 units. Concentrating on the Industrial steam boilers, there are about 45,000 units of which at least 25,000 are over 20 years old. These boilers are on average between 250-400 horsepower, and produce steam at a pressure exceeding 15 psig.

A 400 horsepower high pressure steam boiler operating at full capacity and at 100 psig, consumes 17,851,733 Btu/hr with a fuel to steam efficiency of 75%. This is 179 therms of natural gas per hour.

If we assume the cost per therm is a dollar ($1.00) and the boiler operates for 5000 hours during the year, it (burns) $895,000 per year! This is CASH for the business falling under operational expenses. It is a real cost associated with manufacturing a product which then must be sold for a price. Therefore, if we can reduce the (fuel) cost going into the product, and maintain the same price level, we have increased our margin and free cash flow which can then be invested back into the business, paid out in incentives, dividends, improvements, etc.

Unfortunately, we often do not view energy as wealth, but if we manage our boiler energy efficiently, this wealth can be saved and will result in discretionary cash for our business. Energy should; therefore, be tracked and acted upon as closely as any other operating expense. Yet, many businesses consider energy for their boiler as a cost of doing business, raising prices to cover its escalation with no price/value offset. Conversely, if we proactively manage the wealth we are expending on operating our boilers, we will have a competitive advantage over those managers who choose to simply accept boiler operations as a cost of doing business and willingly subject their enterprise to the risk of a volatile energy market.

Going back to our 400 horsepower boiler example, and the 75% fuel to steam efficiency, we can look at this and determine there are certain inefficiencies which cannot be reduced because of physics and the thermodynamics of the boiler system. For instance, convection and radiation losses which account for 1-2%, and some combustion inefficiencies to assure safety. These cannot be eliminated, and in total account for about 3% of the energy conversion loss. This leaves us with a potential of 10 to 11% (boiler) efficiency to recoup ($98,450/ year). Then, using your choice of "financial screens" (Return on Investment, Annualized Cost to Unit of Energy Saved, Life Cycle Analysis, Internal Rate of Return, etc.) we can determine the best alternative for investing our "Capex" dollars; knowing once the energy investment is covered, the payback keeps returning year after year, especially noticeable when energy prices spike.

So far, the focus has been on potential savings applied to the process steam boiler, saying nothing about the **total steam system** less the process equipment. There is another huge savings potential available here (20-30%) in the form of trapped condensate return, flash steam recovery, blowdown heat recovery, vent condensing, etc., but it is a subject for another time. However, some insight on hot water heating systems provides at least a glimpse of how important it is to look at the entire system when considering potential energy dollars to be saved, returning as wealth to the business. We'll look at this later in the article under "Hydronic Heating Boiler."

Commercial Hydronic Heating

As mentioned in the foregoing, we have approximately 160,000 large commercial and industrial boilers out there, 45,000 of which are process steam which leaves approximately 115,000 commercially sized hot water boilers; 69,000 of which are 20 years or older. Many of these are operating at system efficiencies of 60-70% because of poor designs, inadequate control, piping/pumping and radiation deficiencies, excessive cycling, etc., and represent an excellent opportunity to save energy dollars, improving the wealth position of the business.

The answer to this dilemma has often been the use of condensing boilers with touted efficiencies of 90-95%. In many cases these boilers replace existing non-condensing boilers at a considerable CapEx expense when we consider the removal of the old boiler and the cost of replacing it with a considerably more expensive condensing unit. Unless the condensing boiler and the system to which it is applied are properly understood and configured, the outcome can be far less than expected; delivering high CapEx cost and very protracted to nonexistent ROI's.

The solution for properly deciding the choice for a boiler retrofit or replacement is to first evaluate what is the most economic approach regardless if we are considering a process steam or commercial hot water heating application because each involve *specific evaluation criteria* which must be reviewed before taking action. These evaluation criteria impact several disciplines within the steam or hot water heating facility, affecting ***operations*** (present and long term needs, operating hours, downtime impact, load criticality, etc.), the ***physical plant*** (mechanical floor area, physical access, power, piping system, process, operating personnel, etc.) and the ***financial*** budget constraints (Capex available and financial screens for a "GO "status).

RETROFIT OR REPLACE

The Evaluation Criteria will generally include the following with emphasis changing depending on steam or hydronic heating:

1. Age and condition
2. Capacity in pounds of steam per hour or hydronic heating load in Btu's
3. Operating pressure or temperature
4. Hydronic heating with condensing/non-condensing boilers
5. Fuel to steam efficiency and overall hydronic heating efficiency
6. Burner characteristics (fuel flexibility, turndown, fuel/air control, etc.)
7. Control and/or sequencing schemes for steam and hot water
8. Duty (heating, process or both)
9. Removal and install costs

Process Steam Boiler

When looking at the age and condition of a process steam boiler in light of a retrofit or replace decision, the age becomes a distant second in the review process. The most important is the condition of the boiler especially the pressure vessel--- shell, furnace and tubes. These are the body of the boiler including the venous system delivering the heat energy from the burner which is the heart of the package.

If during the annual inspection wherein the waterside and fireside surfaces are revealed, it shows minimal if any signs of heavy scaling, pitting, cracking or stress, the pressure vessel is most probably in good shape, and in a position to deliver many more years of dependable life. This is a testament to the owner/operator of the equipment indicating that proper operating procedures have been followed including an effective water treatment program.

The next step is to run an efficiency check on the boiler. This is done using a good flue gas analyzer which indicates the percent of O_2 in the exit gas, CO, CO_2 and possibly oxides of nitrogen (NO_x). The checks are made after the boiler has stabilized and has achieved its normal operating pressure. Placing the unit in the manual mode, the efficiencies are checked by modulating the fire throughout the entire range of the burner, checking efficiencies as they vary from low to high fire. The readings are then entered into a formula corrected for normal operating conditions, and an overall efficiency is attained. This becomes the basis for determining payback whether the unit is retrofitted or replaced.

Following the efficiency check, if the efficiency is in the 70-80% range, and the pressure vessel has been determined to be in good shape, a modification should be strongly considered, and the burner is the first place to consider upgrading.

If the combustion analysis showed high excess air (8-10% O_2 vs 3-6%) in the mid to high fire ranges, and percentages of CO in excess of 400 PPM (with good being <50 ppm), the burner is a candidate for a major tune-up, an upgrade or replacement. Sometimes an upgrade only involves the air/fuel control of the burner. This normally entails the replacement of single point linkage systems with independent fuel and air actuators (parallel positioning); eliminating the slippage and hysteresis, increasing the repeatability, and load tracking; saving the owner 3-5% on his/her annual fuel bill. This can be a substantial savings when the fuel is costing hundreds of thousands per year; delivering a payback in months rather than years.

On the other hand, the age and condition of the burner may indicate the best solution is the complete replacement of it, properly sized and fitted to the boiler's furnace for optimum radiant heat transfer. At this time we should also look at updating the controls with advanced technologies for not only controlling the burner's safe operation, but also communicating and historically trending its operation, truly managing the energy choices surrounding the boiler, moving to proactive management rather than reactive.

Even if a boiler performs well throughout the efficiency analysis there still may be savings associated with the overall system due to improper sizing of the boiler. Often times, inefficiencies stem from a boiler being oversized for the summer months of the year. During these months, it "loafs" along in low fire most of the time, cycling several times an hour. This is extremely inefficient operation, driving up radiation and convection losses as a percent of input while increasing excess air levels, reducing combustion efficiency. This can severely reduce a boiler's efficiency from a normal full capacity rating of 83% to the low seventies due to excessive cycling and poor combustion. Remember our 400 HP example of what it costs to operate the boiler at 75%, it was $895,000 per year. A 5% improvement would equate to almost $45,000 per year. Considerable cash for the business to invest in a change which returns wealth year after year…..

In this case, the best solution may be the purchase of a small "summertime boiler" properly sized for the reduced load conditions. At this time, consideration should also be
given to a boiler selection providing adequate backup for the larger boiler should it go down during the peak load time in the winter. The annual savings can be considerable with this strategy especially during times of

fuel price volatility and, considering the cost per unit hour of downtime in the plant. This solution can be applied to any efficient boiler with "shoulder" operating months, whether the boiler is a year old, or twenty years old. Even on new design projects, this should be considered as an effective energy solution strategy.

Finally, we find a boiler which has reached the end of its useful life; poor pressure vessel condition and overall poor performance.

Considering a boiler on average consumes four times its cost in fuel every year, the selection of the new boiler replacement needs to be well thought out involving all disciplines mentioned above; operations, physical, and financial. It is here where the boiler purchase needs to be evaluated on a true price/value basis using the financial disciplines mentioned earlier, especially life cycle costing.

This means the duty load now and in the future needs to be considered along with all of the energy and operational needs the boiler may be called upon to handle such as swing conditions, steam quality, burner turndown, boiler control schemes, emission limitations and credits, domestic and CIP water needs, guaranteed efficiencies, local service/parts, local training, and the cost for old boiler removal and replacement.

These are all important factors which weigh into the final decision, but if done correctly, return wealth to the business year after year…..Call it a boiler energy annuity.

Hydronic Heating Boiler

Now let's turn our attention to the existing hydronic heating system with boilers that have been designed not to condense, operating at system temperatures of approximately 180 to 200 degrees F, and return water temperatures between 160-180 degrees F.

In these cases we are looking primarily at overall system efficiency sometimes referred to as Annual Seasonal Efficiency (ASE) including piping pickup/loss factors, boiler thermal efficiency, outdoor air adjustments, radiation/convection losses, and cycling losses. It is here where some engineers make the quick decision to replace old (20 year) boilers with higher efficiency condensing boilers giving little thought to the operating conditions of the system and what will be required to realize the full savings potential of these new units.

If the new boilers are allowed to operate most of the time at higher design temperatures, 180 supply and 160 return, the condensing boiler will not condense and the savings associated with the higher efficiency of condensing boilers will not be realized. Taking into account a condensing boiler's15-20% higher capital investment compared to a non-
condensing unit, the loss of efficiency due to it not condensing will negate the expected ROI while robbing the business of significant wealth.

In order for the boilers to condense, the system would have to operate at a lower temperature of around140 degrees F with a return of 120-130 degrees. In practice, this may be fine, but care must be taken up front to assure at least adequate coil surface in the air handlers for comfort at these lower temperatures, and if domestic water is being supplied indirectly through the boiler, this be rationalized properly to affect the design requirement.

In this case do we retrofit or replace? Maybe neither. Rather, we may supplement.

THE HYBRID HYDRONIC HEATING PLANT

A hybrid boiler plant is defined as a hydronic heating plant combining condensing and non-condensing boilers. This system is designed to take advantage of the best properties of both types. Through the proper design and selection, we may be able to save the same amount of energy associated with a properly designed full condensing plant with a hyrid system at a cost of one third to one half of an all condensing plant. Hybrid boiler plants may also include alternative fuel boilers such as electric/electrode units. In these cases, the use of one over the other may be driven by the instantaneous cost of the fuel, triggering the use of the least expensive. Monitoring of the cost of delivered fuel can drive the switch-over between operating boilers, and should be part of the operating procedure.

Where to use hybrid systems

One of the main stumbling blocks in using non-condensing boilers in higher efficiency designs has been the higher return water temperature requirements. As mentioned, in most applications water has to be returned to the boiler at or above 140F in order to prevent flue gas condensation from occurring. The dew point of exhaust gases is normally in the range of 135F.

Hybrid plants can be utilized in legacy/existing plants or new designs. Depending on the condition of existing boilers, older, non-condensing boilers could be incorporated into the design and significantly reduce the overall project cost, provided their pressure vessel and burner are in acceptable shape after inspection. Creating an energy solution that combines the ideal number of condensing and non-condensing units can then lead to reduced fuel consumption in excess of 40% when compared to existing systems or all new non-condensing systems. The main benefit leading to this savings is the reduction of boiler cycling while satisfying all the design requirements for comfort, domestic water, snow melting, etc.

The heating profile of many buildings looks very similar to Figure 1. Within this profile, the maximum heating load occurs in the winter months. However, when you look at the fuel consumed normalized against a unit of consumption such as heating degree days, it becomes evident that we consume more heat per heating degree day in the off-peak months such as October and April. The leading contributor to this is the on-off cycling of boilers as the PID (Proportional-Integral-Derivative) loop cannot be maintained within acceptable parameters resulting in what is often referred to as "short cycling."

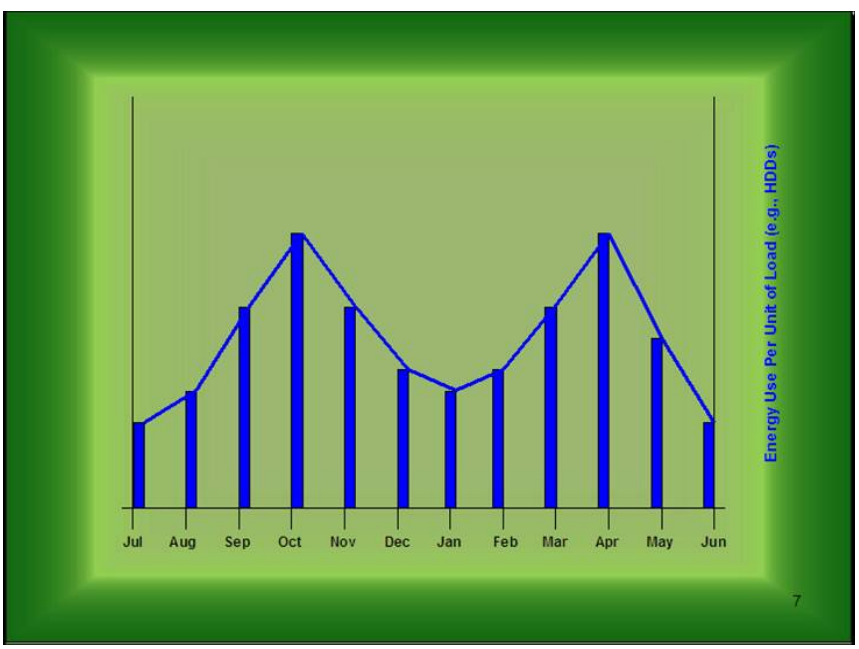


Figure 1

Two (2) control concepts lead to the ultimate savings within a boiler system. See the green theoretical curve in Figure 2. The first area to consider is that of flow intelligence (patent pending). Current control schemes are based on PID temperature controls. This was a great improvement over older systems, but with the leap forward of software processing power, calculated BTU heating load consumption is lending itself to matching the exact heat profile needed instead of chasing the temperature change. In other words, as Btu's are lost in the system, they are immediately recovered through mass flow balancing.

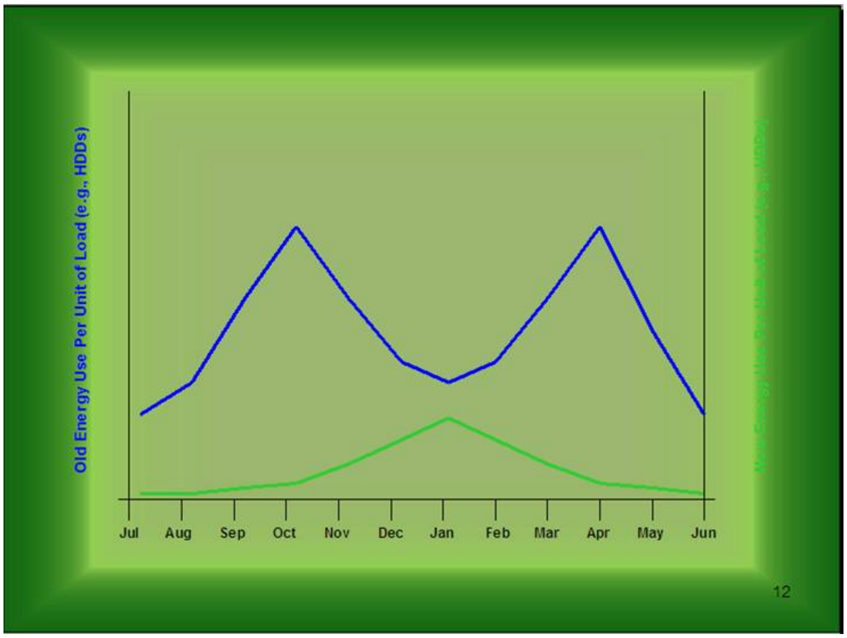


Figure 2

With the use of this applied control, needless cycling of the boilers are greatly reduced if not eliminated. Under current control scenarios, on-off cycling of boilers at low load conditions, chasing PID loop temperatures, can reduce boiler efficiency by 20-30%. Even with a condensing boiler at low return temperatures, theoretical efficiencies of 95% can drop to as low as 65% under these high cycling conditions. Through the use of system delta T and flow rate, the actual consumed heating load can be calculated. Theoretical energy savings; therefore, is the difference between the curves in Figure 1 and Figure 2.

The second concept to consider is that of intelligent load sharing. With a properly sized boiler, run cycles can be limited to two (2) cycles an hour (or less) under no-load conditions. To accomplish this, a small boiler is sized to allow 30 minutes of run time under no load conditions (Delta T x 500). Given the system volume and the delta T of the boiler operating set point, the minimum firing rate can be calculated. With this minimum firing rate, a boiler with appropriate turndown can be selected to achieve this outcome; picking up the minimum losses as they are occurring. During most evaluations this usually turns out to be a smaller boiler than the rest of the units attached to the heating plant. This smaller boiler then becomes similar to the "summer boiler" concept used in steam plants. In those cases, and as mentioned previously, the small steam boiler is used to carry light loads such as the heating load being removed in the summer leaving a small process load. An example could be the steam used for sterilization, and/or humidification in a hospital.

To accomplish the intelligent load sharing, the heating plant control must be able to calculate the load consumed and recognize the maximum and minimum capacity of each boiler attached to the heating plant. With this knowledge, the controller must also be able to further turn on and off modulating boilers to exactly match the load. With current designs, the sizing and control schemes using temperature variation only (without mass flow calculating/selection) usually employ multiple boilers of equal size resulting in considerable on-off cycling as the load drops below the minimum turndown of these similarly sized units.

This is extremely inefficient due to the frequent pre and post purge losses; saying nothing about the stresses on the mechanical equipment leading to higher incidences of (costly) repair and downtime.

How it works

In hybrid systems, the use of condensing boilers occurs when heating loads drop to around 32-35F degrees outside air temperature. In the northern climates, this will account for approximately 75-80% of the heating season, and around 1/3 of the heating load. Actual loads will need to be verified using load calculation software or existing load profiles.

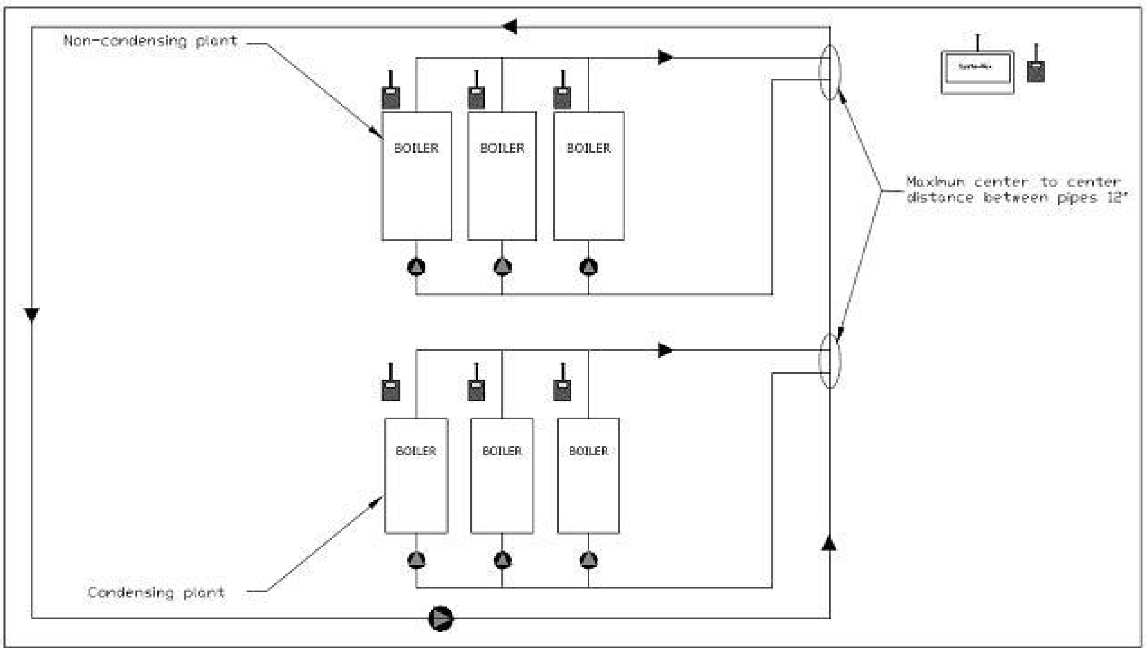
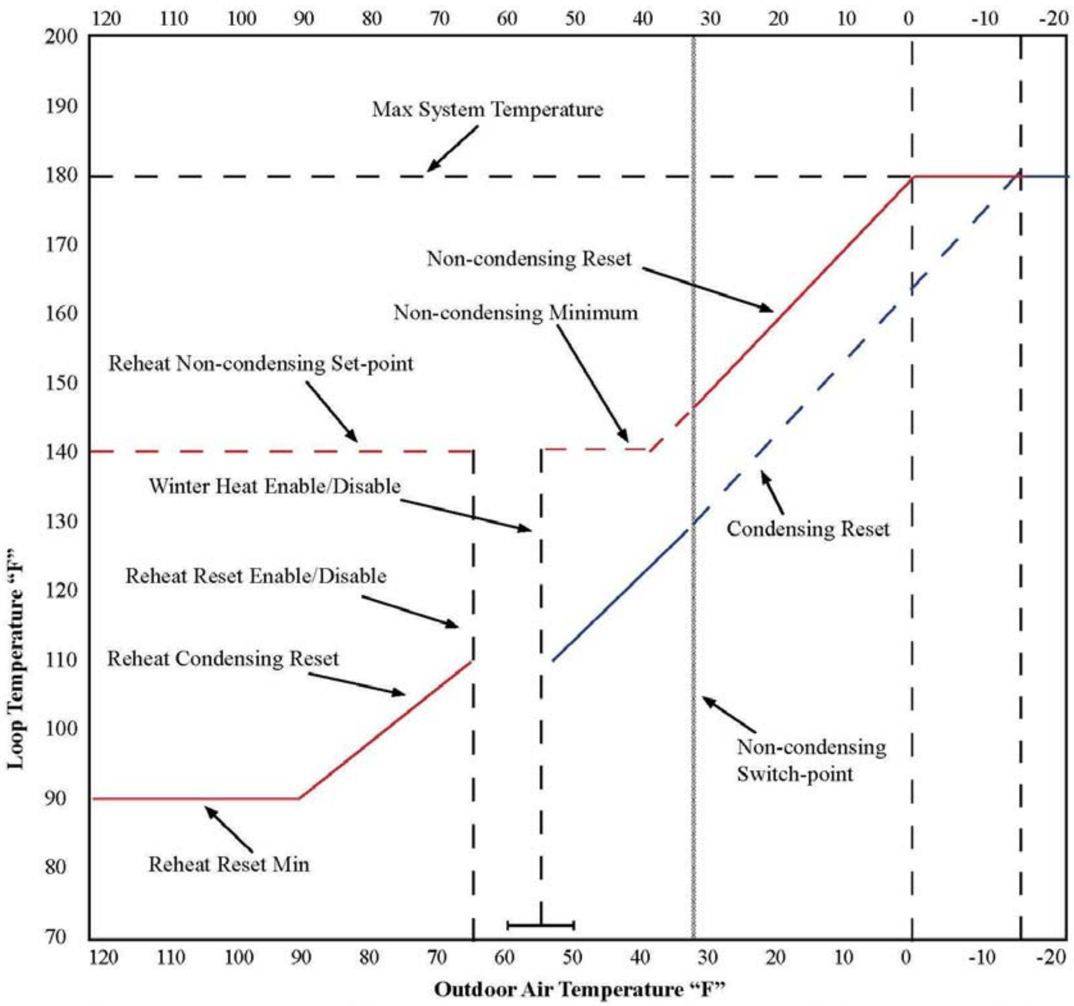


Figure 3

As the heating load increases with an outside air temperature drop, a change over to the non-condensing boilers will provide heat for the incremental increase in demand. Built-in algorithms will enable the transition from condensing to non-condensing units. See Figure 3 for possible piping. Under this configuration, the outputs of the condensing boilers are driven up to above 140F. This will ensure that the inlet to the non-condensing boilers are adequate to prevent condensing in the unit. See Figure 4 (reset curves).



Graph shows Reset Slope 1 (Condensing), Reset Slope 2 (Non-condensing) and Reheat Reset (Condensing or Non-condensing) in a hybrid arrangement. All Enable/Disable points on the graph have a two degree range to eliminate rapid on/off toggle. System will operate assigned reset during a given temperature range unless conditions exist that require a boiler designated as non-condensing to operate in order to meet the heating needs. Night set-back and morning boost will be restrained within the minimum and maximum limits of a given reset slope.

Figure 4

As the load increases (increasing heat loss), the non-condensing boiler will assume the load. If the non-condensing units are sized for 2/3 of the load, the condensing boilers can supplement when a smaller load is needed or during the most severe conditions. If more than one non-condensing unit is used, the control can also change or sequence the operating units in a lead/lag setting to equalize run time. The use of non-condensing boilers thereby allows higher temperature (more Btu's) for colder design day temperatures of the legacy building. Incorporating this concept into new designs also allows higher supply temperatures to keep the heating coil surface in reheat boxes to a minimum, and also accommodates the use of indirect domestic hot water heating should that be part of the design scheme.

What is a good candidate for a hybrid existing system?

A ready source of determining a good candidate for a hybrid system is the burner management system sometimes referred to as the flame safeguard. Many units keep track of the cycles and run hours. If it can be determined that units are cycling excessively, the system is a good candidate for a hybrid design. Many boiler rooms can be shown to have cycles upwards of 10-40 per hour. This is indicative of an over sized heating plant during small loads, and may show up as customer complaints of excessive cycles. Other indicators can be complaints of excessive maintenance requirements, frequent downtime, and customer perceptions of general frustration, either in fuel bills or performance of the system.

Referencing Figures 1 and 2, the potential energy savings are shown as the difference between the blue and green lines. The captured savings will be greater in the off peak months such as October and April. Systems in moderate or mid range climates will have a higher potential for savings and will generally lead to a higher overall return because of more operating hours in off peak months. Warmer climates still have the potential for savings by taking advantage of the summer reheat schedule (Figure 4).

Average Seasonal Efficiency (ASE) for a traditional non-condensing boiler plant has been shown to be 65-70%. This is mainly due to the on-off cycling in the off peak design seasons. ASE using condensing boilers exclusively, (properly designed, sized, and controlled) could reach as high as 93%. However, a properly designed hybrid system could reach these levels at a lower installed cost compared to an all condensing plant.

Finally, when evaluating the use of hybrid systems, savings of 20% should be the minimum expected though savings as high as 40-50% can be realized. Additionally, these systems can reach these levels without changing the higher supply temperature during design day conditions. The final result is retrofit applications which are more affordable with shorter payback; combining condensing boilers with new (or existing) non-condensing units; achieving the best of both worlds.

SUMMARY:

As energy prices continue to vacillate, and we consider the significant cost associated with fueling and maintaining steam and hot water boilers, it is important we be mindful that the energy cost represents wealth to the business, an investment which can be maximized and returned or, wasted.

A decision on whether to retrofit or replace boilers, optimizing fuel usage in the process, involves decision making on the part of operations, the physical plant and the financial people associated with the business, leveraging their combined needs for the long term best interest of the organization. This may result in nothing more than a modification to the existing equipment, it may mean a total replacement of the existing boiler(s). In either case, it should be an informed decision predicated on the life cycle cost of the boiler(s) and what packaged system offers the greatest rate of return over the life of the equipment.

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