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FEAP: Heat Recovery at Industrial Facilities

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Performance of a Condensing Heat Exchanger in Recovering Waste Heat From a Natural Gas-Fired Boiler

by
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The performance of boiler heat exchangers is limited by the need to keep the flue gas temperature above its dew point to avoid condensation of corrosive acids. Sensible heat can be recovered from the flue gas, but latent heat is rejected. However, latent heat can be recovered at temperatures below the dew point of the gas by protecting the heat exchanger tubes from the acids. Teflon™ coatings that previously had been used in heat exchangers did not adhere well. A new Teflon™ covering process demonstrates significant advantages over older coating technologies.

To evaluate the effectiveness of this new Teflon™ covering for use in Army boilers, researchers selected the Louisiana Army Ammunition Plant (LAAP) as a demonstration site. A natural gas firetube boiler with a nominal firing rate of 20.5 million British thermal unit per hour (MBtu/h) and less than 10 percent condensate return was fitted with a Teflon™-covered condensing heat exchanger to preheat makeup water. The average load of the boiler was 5 MBtu/h and the flue temperature was between 350 and 380 °F. The heat exchanger was evaluated through a four-step process: (1) baseline definition, (2) development of test parameters, (3) data collection, and (4) data analysis. Tests were run to determine fuel consumption with and without the heat recovery system operating. At the start of the project, the simple payback was estimated to be 2.8 years on a $63,000 investment, based on a price for natural gas of $4.11/MBtu. Prices subsequently fell and the new simple payback is estimated at 4.8 years based on $2.45/MBtu. The heat exchanger is recommended for installation in similar types of boilers. A simple method for screening potential applications is presented as an appendix.

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The performance of boiler heat exchangers is limited by the need to keep the flue gas temperature above its dew point to avoid condensation of corrosive acids. However, latent heat can be recovered at temperatures below the dew point of the gas by protecting the heat exchanger tubes from the acids. A new Teflon(TM) covering process demonstrates significant advantages over older coating technologies.

To evaluate the effectiveness of this new Teflon(TM) covering for use in Army boilers, researchers selected the Louisiana Army Ammunition Plant (LAAP) as a demonstration site. A natural gas firetube boiler with a nominal firing rate of 20.5 million British thermal unit per hour (MBtu/h) and less than 10 percent condensate return was fitted with a Teflon(TM)-covered condensing heat exchanger to preheat makeup water. Tests were run to determine fuel consumption with and without the heat recovery system operating. The initial simple payback was estimated to be 2.8 years on a $63,000 investment, based on a price for natural gas of $4.11/MBtu. Prices subsequently fell and the new simple payback is estimated at 4.8 years based on $2.45/MBtu.

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FOREWORD

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System design, installation, and monitoring was conducted by Richard Caron, Sharon Jones DeVelle, and Kevin Fitzgerald of Arthur D. Little, Inc., under the direction of the U.S. Army Construction Engineering Research Laboratory, Energy Systems Division (USACERL-ES). Dr. G.R. Williamson is Chief, USACERL-ES. The Technical Editor was Gloria J. Wienke, USACERL Information Management Office.

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LTC E.J. Grabert, Jr. is Commander of USACERL, and Dr. L.R. Shaffer is Director.

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PERFORMANCE OF A CONDENSING HEAT EXCHANGER IN RECOVERING WASTE HEAT FROM A NATURAL GAS-FIRED BOILER

1 INTRODUCTION

Background

The Facilities Engineering Application Program (FEAP) promotes Army demonstrations of state-of-the-art commercial technologies that, although theoretically cost effective, might not otherwise be tried at Army facilities because of their novelty. The use of Teflon™-covered condensing heat exchangers in Waste Heat Recovery Systems (WHRS) on process heat boilers is one such technology. Previously, the perfo⁻.ıance of boiler heat exchangers was limited by the need to maintain the flue gas temperature above its dew point to avoid condensation of corrosive acids. This meant that only sensible heat could be recovered from flue gases; the latent heat of condensation carried by liquid vapor was rejected to the atmosphere. Heat can be recovered at temperatures below the dew point of the gas by protecting the heat exchanger tubes from the acids. Early attempts to coat heat exchanger tubes with Teflon™ were largely unsuccessful because of poor coating adhesion. A new Teflon™ covering process that does not rely on adhesion has been introduced by the CHX Corporation of White Plains, New York. This process uses Teflon™-to-Teflon™ mechanical seals at the tube/tube-sheet interface. Teflon™-covered heat exchangers have been successfully installed and operated by CHX and other companies at many commercial sites in the United States, but are not in widespread use at Army industrial facilities.

Objective

The objective of this work was to demonstrate the effectiveness of a Teflon™-covered condensing heat exchanger when used as part of a WHRS on a gas-fired process steam boiler at an Army facility. In addition, the study is expected to help Army managers evaluate the potential for condensing heat exchangers at other sites through correlations between projected heat exchanger performance, heat sink capacity, and boiler efficiency.

Approach

Following a survey of candidate sites for waste heat recovery at Army Materiel Command (AMC) facilities[1], researchers chose the Louisiana Army Ammunition Plant (LAAP) as the site for demonstrating operation of a Teflon™-covered condensing heat exchanger on a WHRS. During this project, researchers developed a procedure for assessing other candidate sites for waste heat recovery (Appendix). A simple payback projection of less than 5 years was used to select LAAP as the demonstration site.

The condensing heat exchanger was evaluated through a four-step process: (1) baseline definition, (2) development of test parameters, (3) data collection, and (4) data analysis.

[1] E.T. Pierce et al., *Heat Recovery at Army Materiel Command (AMC) Facilities*, Technical Report E-88/05/ADA197926 (U.S. Army Construction Engineering Research Laboratory [USACERL], June 1988).

Scope

The results of this demonstration apply to natural gas-fired boilers having little or no condensate return. The maximum recommended (continuous) flue gas temperature for the Teflon™-covered heat exchanger demonstrated by this project is 500 °F (260 °C); higher temperature applications would need to use another type of heat exchanger in the line before the condensing heat exchanger.

Mode of Technology Transfer

The results of this demonstration have been disseminated through the Army Energy Information Exchange Newsletter, and presentations at Industrial Energy User's Group meetings. It is recommended that the procedurc for evaluating processes as WHRS candidates (Appendix) be distributed to Army Energy Managers.

2 SITE DESCRIPTION AND BASELINE DEFINITION

Plant Mission

LAAP, Area C, is assigned the mission to load, assemble, and pack ammunition. Items produced in Area C during this test program included mines, grenades, and harpoons.

Area C needs steam for melting, baking, and curing explosives, spacing heating, and domestic hot water heating. All steam heating functions, both process and personnel related, vary with outdoor temperature. One product shift per day, Monday through Friday, is typical. However, because the trays and carts of explosives must cure for 40 hours, the boiler plant must be steamed continuously from Monday morning until 7:00 a.m. on Sunday morning. During warm weather, the boiler plant is shut down from Sunday to Monday morning.

Power Plant Description

The Area C steam requirement is supplied by a firetube boiler having a nominal firing rate of 20.5 million British thermal units per hour (MBtu/h [6 Mega-watt-hours (MWh)]). It normally operates at about 5 MBtu/h (1.47 MWh), a quarter of its total capacity. The boiler operates approximately 8300 h and consumes 50 million cubic feet (M cu ft [1.42 million cubic meters (M m^3)]) of natural gas annually. The flue temperature ranges from 350 to 380 °F (177 to 193 °C). The boiler uses 90 to 100 percent make-up water, with limited condensate return. Because natural gas has a sulfur content lower than No. 2 or No. 6 fuel oils, it produces less corrosive flue gases. The makeup water is preheated with steam in the deaerator before it is sent to the boiler. Figure 1 shows a simplified system schematic of the boiler in Area C at a normal load condition. The enthalpy values given in parentheses are obtained from steam tables for saturated vapor and liquid. (Heat loss through piping, storage tanks, the deaerator, and the boiler have been neglected in the energy balance shown in Figure 1.) As can be seen, approximately 10 percent of the boiler's out put is sent to the deaerator to preheat feedwater.

Baseline Definition

To assess the impact of adding a WHRS, it was first necessary to establish baseline conditions for the boiler plant. Boiler efficiency and heat exchanger performance variation with load was accounted for by establishing load "bins" within which the efficiency and heat recovery performance could be considered essentially constant. The amount of fuel used in each bin during the baseline period (November 18, 1986 to August 27, 1987) was then determined. For ease of computation, energy units are all expressed in MBtus.

Fuel consumption data from the baseline period were plotted to identify typical boiler loading. A plot of the data, with a curve extrapolated to 1 year based on temperature data is shown in Figure 2. The fuel use rate peaks at about 310 MBtu/dy (90.86 MWh/day) in the winter and gradually decreases to an average of 60 MBtu/day (17.59 MWh/day) in the summer. As expected, outdoor temperature is the major driving force for changes in fuel consumption over the year. Fuel consumption is plotted against outdoor temperature in Figure 3 to illustrate this relationship; the outlying data points represent Sundays and holidays during which the boiler operated only a fraction of the day. This graph was used to extrapolate

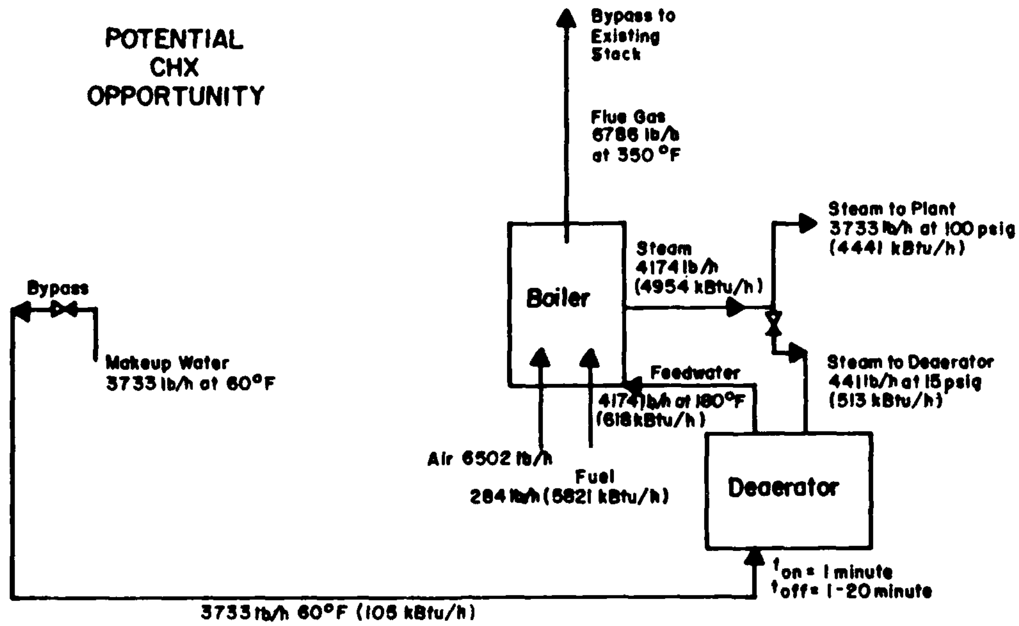
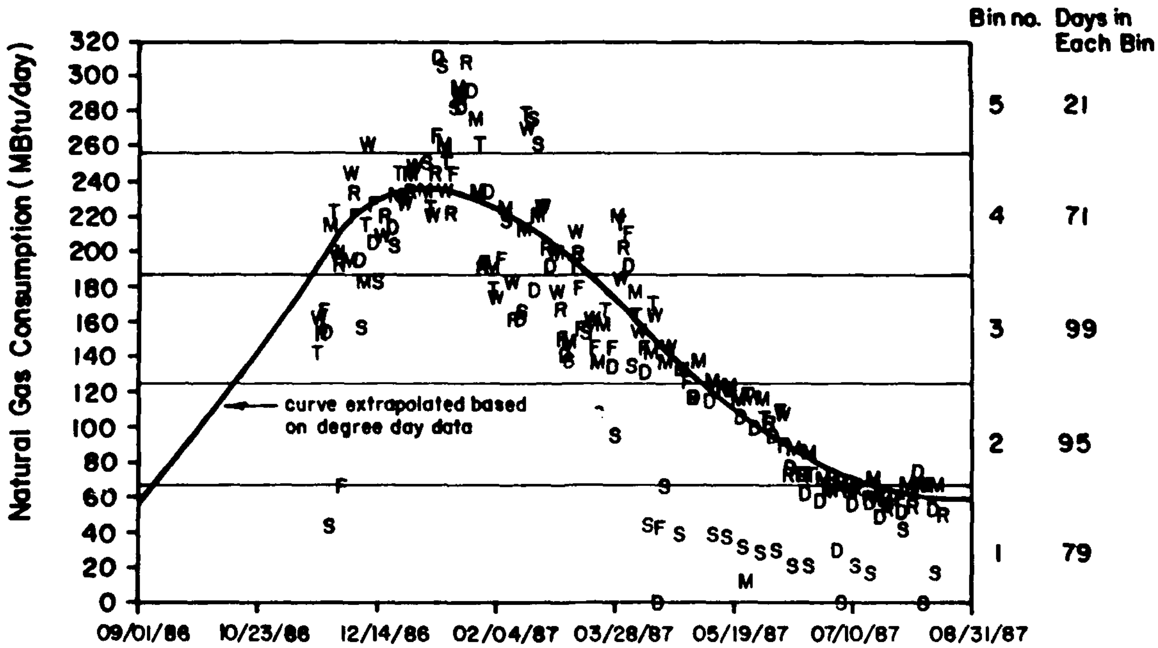


Figure 1. Boiler plant without waste heat recovery.



Notes:
1) Letter indicates day of week; M=Monday, T=Tuesday, W=Wednesday, R=Thursday, F=Friday, D=Saturday, S=Sunday
2) Outlying days of low consumption are Sundays or holidays where boiler operates less than 8 hour/day
3) All other days boiler operates 24 hour/day

Figure 2. Annual fuel consumption profile.

fuel usage over the unmonitored portion of the year, showing that the Area C boiler consumes the natural gas equivalent of approximately 50,000 MBtu/yr (14,655 MWh/yr). Table 1 shows how the load was divided into bins.

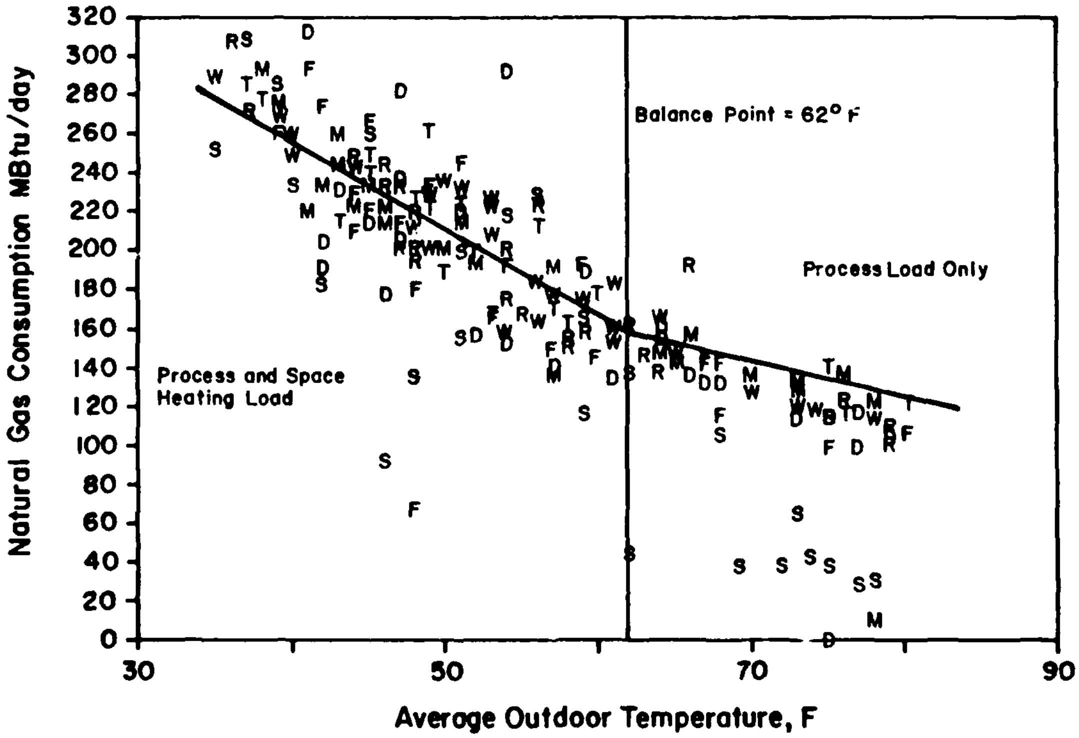


Figure 3. Fuel consumption vs. temperature.

Table 1

Boiler Load Bins

Bin	Load (MBtu/day)
1	0 - 64
2	65 - 127
3	128 - 191
4	192 - 255
5	256 - 320

3 DEMONSTRATION PLAN AND MONITORING METHODS

Waste Heat Recovery System Description

The condensing heat exchanger controls, fan, ducting, and exhaust stack used in this demonstration were provided as a packaged unit by CHX Corporation of White Plains, New York. The exchanger was a shell and tube design in which the flue gases passed through the shell side, and the water to be heated flowed through the tubes. The shell side was completely Teflon™-covered. The condensing heat exchanger reduced flue gas temperature to less than 200 °F (93 °C), the point that sulfuric acid and water vapor condensed on the tubes. Thus, with this heat exchanger design, some of the latent heat of water vapor formed during combustion was recovered. In addition, there are strong possibilities that a condensing heat exchanger could be used in combination with pollution control devices to remove sulfur from flue gases. This would allow lower cost, higher sulfur fuels to be burned.

Figure 4 depicts boiler operation with the heat recovery unit and resulting energy flows at average load conditions. Note that this was a passive installation with no damper or restriction in the existing stack. Instead, flue gases were pulled into the condensing heat exchanger by an induced draft fan. If the WHRS needed to be shut down, the boiler could still be operated as if the WHRS was not installed. The flue gas traveled from the existing exhaust stack through the induced draft fan, down through the condensing heat exchanger, and finally out through a new fiberglass-reinforced plastic stack. A drain was also provided for the water vapor and acids in the flue gas that condensed on the heat exchanger tubes. Since the condensate was highly acidic and could not be drained to the sewer, it was piped to the boiler blowdown sump. Boiler blowdown is highly alkaline and served to neutralize the condensate.

The heat exchanger required a continuous flow of water and flue gases. For boilers, the flow of makeup feedwater is intermittent. To prevent overheating and possible boiling tin the condensing heat exchanger, a storage tank and circulating water loop were included in the system design.

The storage tank was sized for minimum initial cost, subject to the constraint that it be large enough to accommodate low feedwater demand periods. The complete heat recovery system, including an insulated storage tank and 3-wall building addition, was packaged at the factory in New York and trucked to the site. A heavy duty fork lift set the skid-mounted unit in place on concrete piers. Water piping connections and flue gas breeching ductwork were completed and the system was operational approximately 1 week after delivery. The heat exchanger itself consisted of five individual modules in series and was 8 ft high, 5 ft deep, and 5 ft wide (2.5 m high, 1.5 m deep, and 1.5 m wide). The heat exchanger package weighed 2875 lb (1302 kg) dry, and 3625 lb (1642 kg) flooded. The total heat transfer surface area was 515.5 sq ft (48 m^2).

Performance Monitoring

To determine the heat recovered by the WHRS, it was necessary to measure the heat transferred to the boiler makeup water. Knowing the boiler efficiency at each load condition, it was possible to calculate how much additional fuel would have been required to heat the boiler makeup water with steam had the WHRS not been installed. Figure 5 illustrates the variables that were monitored and the location of meters and sensors. By measuring the flow rate and temperature increase of makeup water across the WHRS storage tank, the total energy recovered from the boiler's flue gas could be determined.

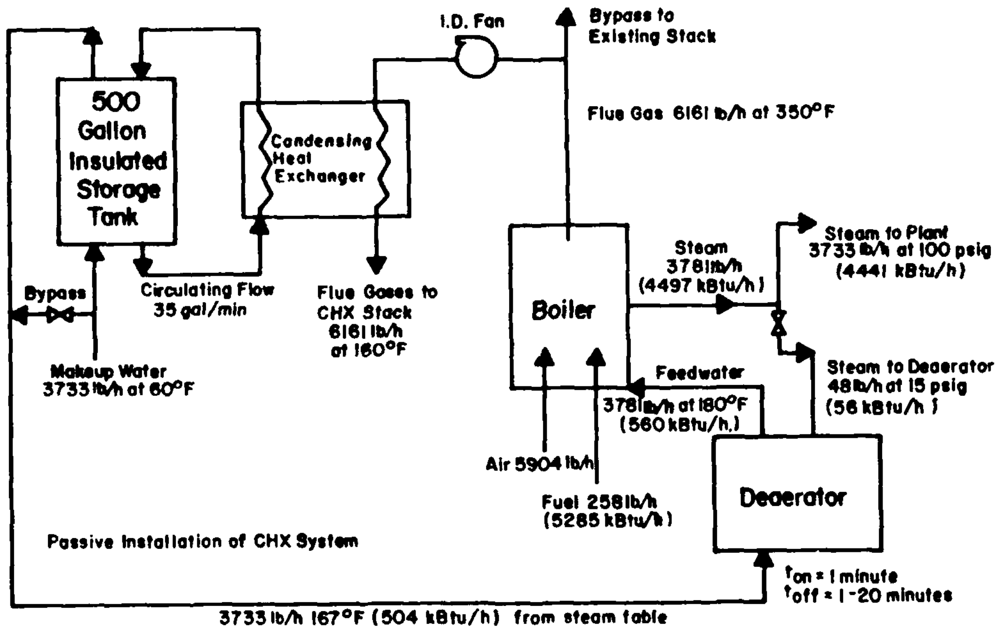


Figure 4. Boiler plant with waste heat recovery.

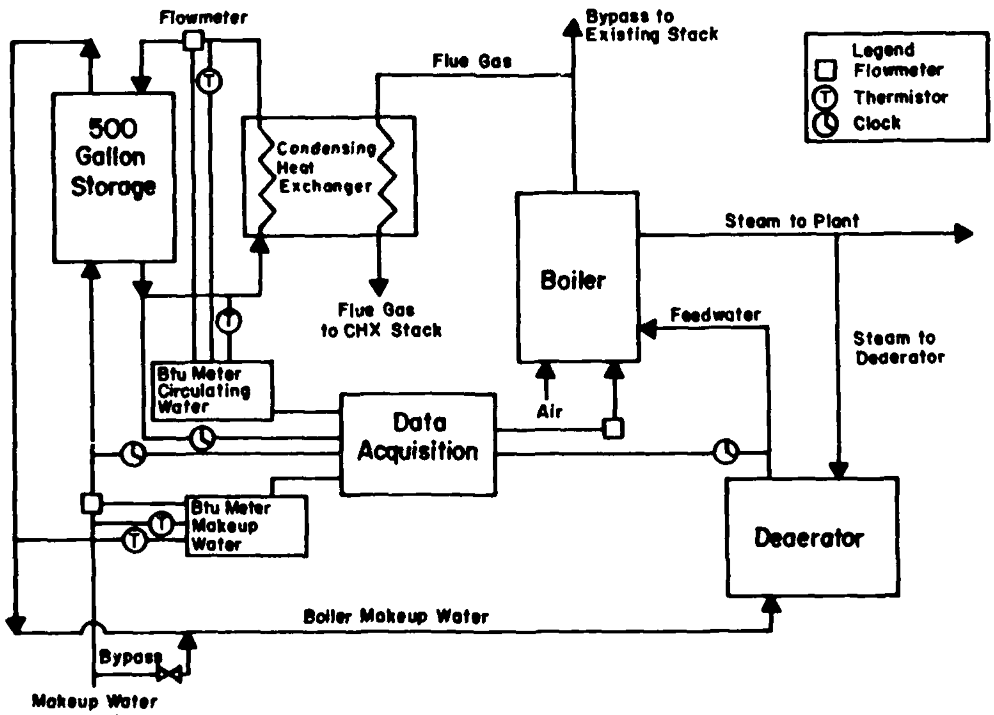


Figure 5. Plant instrumentation.

Instrumentation used for data acquisition is listed in Table 2. In addition to the instrumentation listed, fuel flow was measured by a site-supplied Foxboro vortex-shedding meter. The site personnel supplied information on boiler efficiency as a function of boiler load.

Output signals of makeup water flowmeters and temperature sensors before and after the storage tank were input to a Btu meter that calculated the resulting enthalpy difference. A Btu meter was also installed across the condensing heat exchanger for redundance. Counters and run-time meters were placed on the boiler, feedwater pumps, makeup water solenoid, and circulating water pump for supplemental information. The output of these devices drove electromechanical counters displayed on an electrical panel in the WHRS building. This panel was read by a site engineer daily and recorded by hand.

Table 2

Instrumentation Specifications

Parameter	Type	Manufacturer	Accuracy	Range
Makeup Water Flow and Circulating Water Flow	Nutating Disc	Badger	±1.5%	10-100 gpm
Makeup Water ΔT and Circulating Water ΔT	Thermistor 10 K Ω at 77 °F	YSI	±0.2 °F	32-250 °F
Makeup Water ΔH and Circulating Water ΔH	Digital Staircase Integrating Board	DK Enterprises	±0.4%	0.1-10 MBtu/h

4 ANALYSIS AND RESULTS

Energy Savings

The heat recovered by the condensing heat exchanger is plotted as a function of boiler fuel consumption in Figure 6. As can be seen, the system outperformed the manufacturer's predictions.

The heat recovered by the condensing heat exchanger is used to preheat boiler makeup water, displacing part of the steam load to the deaerator. The fuel savings due to heat recovery (Q_R) are therefore equal to the amount of additional fuel that would have been necessary to produce steam for this load. To find the fuel energy savings (Q_{FS}) attributable to condensing heat exchanger heat recovery, the boiler efficiency (η) within each load bin must be taken into account by using the following equation:

$$Q_{FS} = \frac{Q_R}{\eta} \qquad \text{[Eq 1]}$$

The fuel consumption under baseline conditions, Q_{FCB}, will differ from the fuel consumption with heat recovery, Q_{FC} by the amount of fuel savings.

$$Q_{FCB} = Q_{FC} + Q_{FS} \qquad \text{[Eq 2]}$$

Fractional fuel savings, X, have been defined as a function of baseline fuel consumption:

$$X = \frac{Q_{FS}}{Q_{FS} + Q_{FC}} \qquad \text{[Eq 3]}$$

Defining the fractional fuel savings in this manner allows one to quickly calculate fuel savings for the baseline condition.

Boiler efficiency is also a function of boiler load, as indicated in Figure 7. LAAP supplied boiler efficiency results obtained during a boiler tuneup. (The data points are the midpoints of the bins.) Combining the heat recovery for each bin, $Q_{R,i}$, with the boiler efficiency in that bin, enables calculation of the fuel savings in that bin; recall:

$$Q_{FS,i} = \frac{Q_{R,i}}{\eta_i} \qquad \text{[Eq 4]}$$

To transform bin fuel savings to baseline fuel consumption data, calculate the fractional fuel savings:

$$X_i = \frac{Q_{FS,i}}{Q_{FS,i} + Q_{FC,i}} \qquad \text{[Eq 5]}$$

and

$$Q_{FCB,i} = Q_{FC,i} + Q_{FC,i} \qquad \text{[Eq 6]}$$

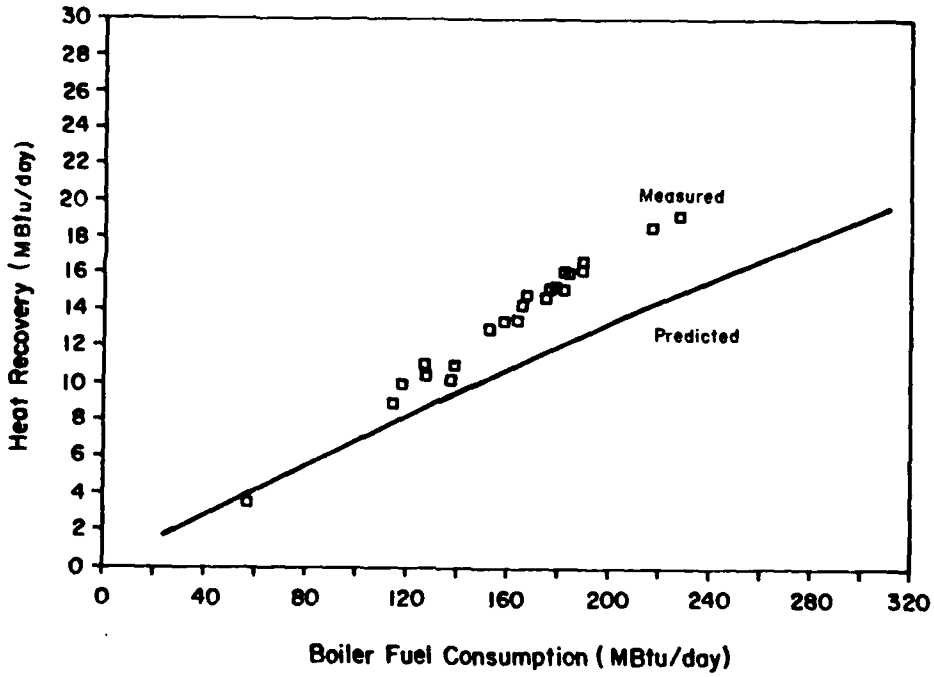


Figure 6. Heat recovery variation with load.

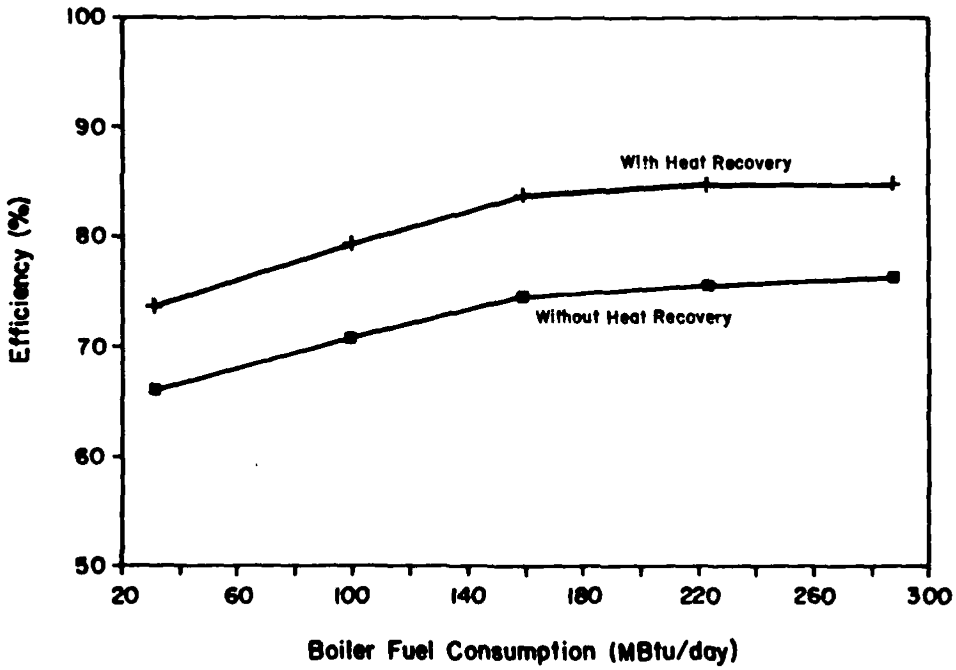


Figure 7. Boiler efficiency variation with load.

The fractional fuel savings is plotted as a percentage against the calculated baseline fuel consumption in Figure 8. Predicted savings are also shown for comparison. Now that fuel savings are available as a function of baseline fuel consumption (without heat recovery), this information can be superimposed on the annual baseline fuel consumption data to yield annual savings. For each bin,

$$Q_{FS,i} = X_i Q_{FCB} \qquad \text{[Eq 7]}$$

So,

$$\text{Total Annual Fuel Savings} = \sum_{i=1}^{5} X_i \, Q_{FCB} \qquad \text{[Eq 8]}$$

The consumption and savings figures for each bin are listed in Table 3. Overall, the WHRS decreased the fuel consumption of the boiler by 10.8 percent.

Cost Savings

The net savings attributable to fuel costs are equal to the value of the fuel saved minus additional operational costs. The price of natural gas was \$4.11/MBtu during fiscal year 1987 (when the WHRS was approved) but dropped about the time of installation (August and September 1987) and was \$2.45 MBtu at the time of this analysis (March 1988). The additional (parasitic) energy cost incurred to operate the induced draft fan, motorized damper, and circulating water pump is estimated as the electric power rating of these auxiliary items (1.037 kW) times the hours of operation and the cost of electricity (5.2¢/kWh). Table 4 shows cost savings at the planning fuel price and at the actual fuel price.

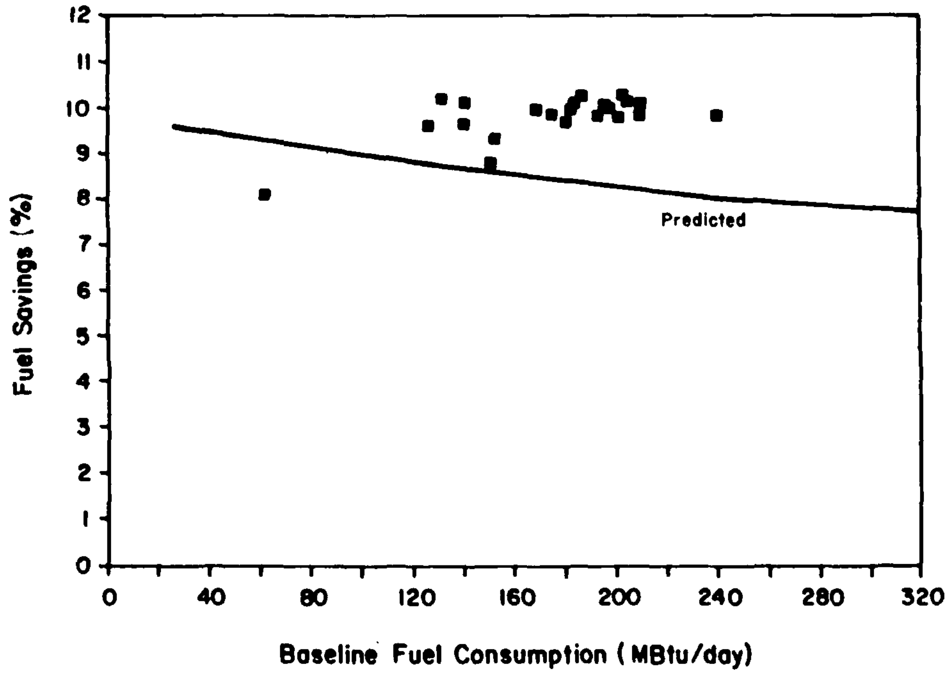


Figure 8. Fuel savings as a function of load.

Table 3

Annual Fuel Consumption and Savings by Bin

Bin	Range (MBtu/d)	Baseline Fuel Consumption (MBtu)	Fuel Savings (%)	Fuel Savings (MBtu/yr)	Total Fuel Savings ($ at $2.45/MBtu)
1	0 - 64	3895	10.3	401	
2	65 - 127	8998	10.7	963	
3	128 - 191	15,686	11.0	1725	
4	192 - 255	15,844	10.9	1727	
5	256 - 320	5,893	10.1	595	
		50,316		5411	13,257

Table 4

Cost Savings

	Actual Fuel Price ($2.45/MBtu)	Planned Fuel Price ($4.11/MBtu)
Fuel Savings, MBtu/yr	5411	5411
Fuel Savings, $/yr	$13,257	$22,239
Parasitic Energy Cost, $/yr	$465	$465
Net Savings, $/yr	$12,802	$21,774

Simple Payback

The cost of the installed system was $67,000. Savings at the fuel price of $2.45/MBtu are $12,797 for a 5-year simple payback. Figure 9 illustrates how fuel prices impact the simple payback period. At the beginning of the project, the price of $4,11/MBtu would have resulted in a 3-year cost recovery period. Even with a 60 percent drop in fuel price, the payback was still within 5 years. It is interesting to note that by February 1990, the cost of natural gas was $2.68/MBtu and rising.

Simple payback analysis is only an adequate decision tool when the resulting payback period is short (i.e., less than 5 years). As the payback period gets longer, other factors such as the time value of money, fuel escalation rates, operating and maintenance costs, and salvage value become more important. The Life Cycle Cost in Design (LCCID) program is the recommended method of carrying out this analysis (Appendix).[2]

[2] Linda Lawrie, *Development and Use of the Life Cycle Cost in Design Computer Program (LCCID)*, Technical Report E-85/07/ ADA162522 (USACERL, November 1985).

Operation and Maintenance

The unit installed in this demonstration experienced a bearing and shaft failure after operating for about 7 months. Although this type of failure is unusual, it does underscore the need for regular maintenance. The manufacturer recommends that the fan be cleaned, and belts and pulleys inspected every 2 months. The bearings on this unit should also be lubricated every 2 months. This regular maintenance schedule is estimated to require about 30 manhours/year. The expense of this maintenance requirement was not included in the economics presented in this report.

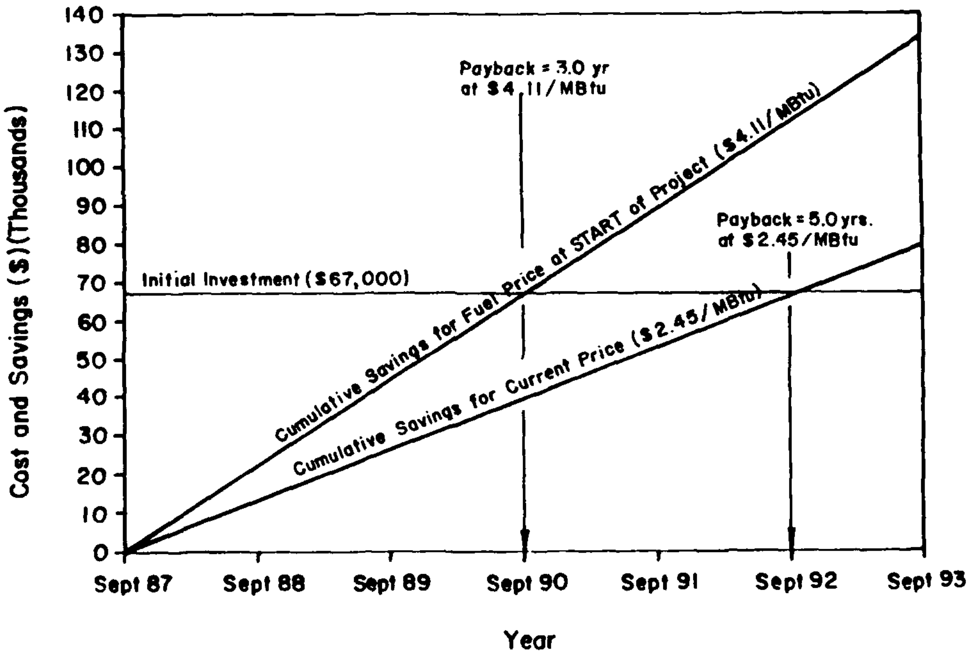


Figure 9. Simple payback analysis.

5 CONCLUSIONS AND RECOMMENDATIONS

The demonstration of the Teflon™-covered condensing heat exchanger at LAAP was highly successful in that it recovered more heat than predicted by the manufacturer. The overall improvement in boiler fuel efficiency was 10.8 percent. This means that the $67,000 system will pay for itself in less than 5 years. In regions with higher fuel prices, simple payback periods of less than 3 years should not be uncommon. The LAAP boiler which this condensing heat exchanger was installed on was fueled by natural gas, which does not have corrosive effects as serious as No. 2 or No. 6 fuel oils, so the results of this demonstration should not necessarily be applied to more corrosive boiler installations. The manufacturer does not report, however, that in October of 1988, 80 percent of the 93 condensing heat exchanger units sold were installed on boilers burning No. 6 fuel oil.

It is important to perform housekeeping measures prior to installation of heat recovery systems. Although a waste heat recovery device will show higher savings when boiler efficiency is low, it is preferable that the fuel not be "wasted" on the front end.

The recommended practice for installations that have potential waste heat recovery applications is to first survey the installation's physical plant using the procedure outlined in the Appendix. If well matched heat sources and sinks are available with a simple payback of 5 years or less, then the LCCID computer program should be used to calculate the life cycle cost savings potential of the project. This is not to say that projects with a payback greater than 5 years should not be examined, but priority should be given to applications with a shorter payback period. If the project is still attractive, then the single most important factor in designing, procuring, and installing the system is to specify a high quality condensing heat exchanger that will withstand the corrosive flue gases of the fuel to be burned.

METRIC CONVERSION TABLE

1 cu ft	=	0.0283 m^3
1 ft	=	0.305 m
1 lb	=	0.453 kg
1 MBtu	=	0.2931 MWh
1 sq ft	=	0.093 m^2
(°F-32)0.55	=	°C

APPENDIX:

ESTIMATING CONDENSING HEAT EXCHANGER APPLICABILITY TO OTHER BOILER BLANTS

Many boiler plants within the Corps of Engineers could benefit from adding a condensing heat exchanger waste heat recovery system. Boilers without economizers and little or no condensate return offer the greatest potential for heat recovery. Evaluation of a potential condensing heat exchanger application follows a simple four-step process:

1. Identify heat sources

2. Identify heat sinks

3. Match loads

4. Calculate savings and simple payback.

The procedure outlined below gives a preliminary evaluation of whether a potential application is worth further consideration. If so, a more detailed analysis should be performed.

Identify Heat Sources

When fuel is burned in a boiler, the heat produced is used to produce steam, is lost by conduction through the boiler walls, or is exhausted in the flue gases. The boiler efficiency, which varies according to the output demanded of the boiler, allows one to determine how much of the supplied fuel is converted to steam. For a first pass analysis, losses through the boiler walls can be neglected and the heat source quantified as whatever is not converted into steam. Although this will overstate the amount of heat available, the result is still useful in determining whether further analysis should occur. If the results of this analysis indicate a cost effective project, a more detailed analysis will reveal a higher cost effectiveness.

For example, the load profile of a boiler has been divided into winter and summer bins of similar boiler efficiences (Table A1). For instance, a boiler might normally operate at two firing rates, with a summer average boiler efficiency of 80 percent and a winter efficiency of 76 percent. The energy available for each bin (Q_H) is a function of fuel use rate (F_{in}), boiler efficiency (η_B), and operating hours (ΔT):

$$Q_H = F_{in}\Delta T(1 - \eta_B) \qquad \text{[Eq A1]}$$

Table A1 shows that for this example problem, the energy available in the winter bin is 19,443 MBtu and in the summer bin is 7647 MBtu. This example assumes that only the heat from one boiler would be recovered, but it is often the case that flue gases from two or more boilers could feasibly be ducted to the same condensing heat exchanger.

Table A1

Load Matching Analysis

Winter:		
fuel use rate, kBtu/h	22,256	
boiler efficiency (%)	80	
operating hours, h	4368	
energy available, MBtu		
$\left[\frac{22{,}256\text{kBtu}}{\text{h}}(1-0.80)4368\text{h}\right]$		19,443
Summer:		
fuel use rate, kBtu/h	7809	
boiler efficiency (%)	76	
operating hours, h	4080	
energy available, MBtu		
$\left[\frac{7809\text{kBtu}}{\text{h}}(1-0.76)4080\text{h}\right]$		7647
Total Energy Available, MBtu		27,090

Identify Heat Sinks

First identify liquid streams that could be heated with a condensing heat exchanger. In the case of a boiler with limited or no condensate return, the makeup feedwater stream is a good candidate. For cost efficiency, consider flows that pass through the boiler room or adjacent buildings first. Note the cold temperature (T_{in}), the hot temperature (T_{out}), and the mass flow rate (m in pounds per hour) for each stream. The energy required in each bin (Q_L) is:

$$Q_L = mc(T_{out} - T_{in}) \qquad \text{[Eq A2]}$$

where c = the heat capacity of water (1 Btu/lb_m- deg F).

Table A2 shows the energy requirement to preheat makeup feedwater for the boiler used as a heat source in A1.

Match Loads

The most important factor affecting the ability of the heat sink to use heat provided by the heat source is that the heat source must be available in a form that is usable by the heat sink. To use an obvious example, the temperature of the heat source must be higher than T_{out} required by the heat source, or only a portion of the heat source may be used. Also, the lower T_{out} is, the more effectively heat can be transferred to the heat sink. This is why it is better to heat makeup feedwater, which usually has a T_{in}

Table A2

Heat Source Determination

Winter:		
flow rate, lb/h - m	12,000	
hot temperature, F-T_{out}	180	
cold temperature, F-T_{in}	60	
operating hours, h	4368	
energy need, MBtu		
$\left[\frac{12{,}000\text{lb}}{\text{h}}(180-60)\text{F}\frac{\text{kBtu}}{\text{lbF}}4368\text{h}\right]$		6290
Summer:		
flow rate, lb/h - m	4000	
hot temperature, F - T_{out}	180	
cold temperature, F - T_{in}	65	
operating hours, h	4080	
energy need, MBtu		
$\left[\frac{4000\text{lb}}{\text{h}}(180-65)\text{F}\frac{\text{kBtu}}{\text{lbF}}4080\text{h}\right]$		1877
Total Energy Requirements, MBtu		8167

equal to the ground water temperature, than to heat condensate return, which is considerably hotter. Assuming that the above prerequisites are met, the maximum energy savings for each bin are:

$$Q_{saved} = \text{the lesser of } Q_H \text{ or } Q_L \qquad \text{[Eq A3]}$$

Table A3 gives the results for the example problem. The annual energy savings are found by summing the energy savings for each bin.

Calculate Savings and Simple Payback

Cost savings are found by multiplying the quantity of fuel that would have been burned to produce Q_{saved} (taking the annual weighted average boiler efficiency into account) by the cost of the fuel:

$$\text{Savings} = \text{Fuel Cost x } Q_{saved}/\eta_B \qquad \text{[Eq A4]}$$

Simple payback (S) is found by dividing the initial cost of the system by the annual cost savings:

$$S = (\text{system cost})/\text{Savings} \qquad \text{[Eq A5]}$$

Table A3

Cost and Savings

Energy Transfer	
Winter, MBtu	
min [6290, 19443]	6290
Summer, MBtu	
min [1877, 7647]	1877
Total Energy Requirements, MBtu	8167

The cost of equipment and installation is site-specific. However, some factors that affect installation costs are:

1. The need for a holding tank and recirculation loop to accommodate load mismatching or batch flows

2. Extensive ductwork necessary to connect more than one boiler

3. Additional (water-water) heat exchangers to accommodate hot water temperature needs of different streams or for segregating softened water from city water

4. Physical space accessibility; can the condensing heat exchanger be installed on the boiler roof? In a building addition? Is structural work required to place the unit in the boiler room?

Is Further Analysis Justified?

Generally, if the condensing heat exchanger application being considered has a simple payback of less than 5 years, a more detailed analysis is highly recommended and the system has a high probability of providing a quick return on investment. If the simple payback is between 5 and 10 years, other factors such as the time value of money, fuel escalation rates, operating and maintenance costs, and salvage value become more important. The Life Cycle Cost in Design (LCCID) program is the recommended method of carrying out this analysis. It is available through the BLAST support office at the following address:

BLAST Support Office
144 Mechanical Engineering Building
1206 West Green Street
Urbana, IL 61801

A simple payback period greater than 10 years does not mean that the project is not worth doing. However, it is important to realize that an LCCID analysis will probably reveal a fairly low LCC savings. It may be difficult to justify additional engineering analysis and design time. If other options are more attractive, do them first.

Other Examples

In the example given, there is only one boiler plant serving as a heat source and the heat sink is the cold makeup water serving the same boiler. Boiler loads are lighter in the summer, so there is less heat available for recovery. Since less steam is required, less makeup water is required to be heated. Ground water temperature is also higher in the summer, requiring less preheating before injection as makeup feedwater. In the winter, the opposite is true, since high steam loads require large amounts of makeup feedwater. The loads are well matched not only throughout the year, but also on a day-by-day and hour-by-hour basis.

It is possible and often practical for a heat exchanger to recover waste heat from the flue gas of several boilers and to use this heat to preheat not only makeup water, but also laundry water, domestic water, and/or process water. Condensing heat exchanger applications have also included preheating combustion air, although this is less common. Table A4 gives sample calculations for four hypothetical cases. Cases 1 and 2 are straightforward. Case 3 has an insufficient load to effectively use the heat available from the condensing heat exchanger. Case 4 depicts a system that uses the heat from one boiler to preheat feedwater for four boilers.

Table A4

Cost and Savings Expected for Hypothetical Applications

Case	1	2	3	4
Description	20% Condensate Return Makeup Water (1 boiler)	Heat Domestic Hot Water (1 boiler)	80% Condensate Return (1 boiler)	One Boiler Heats Feed-water for Four Boilers With 80% Condensate Return
Heat Sink				
Winter:				
flow rate, lb/h	12,000	33000	3000	12000
hot temp, F	180	120	180	180
cold temp, F	60	60	60	60
operating hours, h	4368	4368	4368	4368
energy need, MBtu	6290	8650	1570	6290
Summer:				
flow rate, lb/h	4000	33000	1000	4000
hot temp, F	180	120	180	180
cold temp, F	65	60	65	65
operating hours, h	4080	4368	4080	4080
energy need, MBtu	1880	8650	470	1880
Total	8170	17300	2040	8170
Heat Source				
Winter:				
fuel use rate, kBtu/h	22,256	22,256	22,256	22,256
operating hours, h	4368	4368	4368	4368
boiler efficiency %	80	80	80	80
energy available, MBtu	19440	19,440	19,440	19,440
Summer Operation:				
fuel use rate, kBtu/h	7810	7810	7810	7810
operating hours, h	4080	4080	4080	4080
boiler efficiency %	76	76	76	76
energy available, MBtu	7467	7647	7647	7647
Total Energy Available, MBtu	27090	27,090	27,090	27,090
Annual Energy Savings, MBtu	8170	17,300	2,040	8170
Annual Average Boiler Efficiency	79	78	79	79
Annual Savings, $ @2.50/MBtu	25,854	55,949	6457	25,854
Approximate Cost	70,000	75,000	70,000	80,000
Simple Payback	2.7	1.4	10.8	3.1

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