Measured Performance of a Direct-Contact Heat Recovery System Installed at a Commercial Bakery

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ABSTRACT

Many industrial processes can benefit from heat recovery. This paper presents measured results from a direct-contact heat recovery system installed at a large commercial bakery in Brooklyn, NY. The wet-spray, direct-contact system recovers heat from the exhaust stack of a gas-fired commercial baking oven. Heat is transferred to the water via mass and heat exchange in a packed tower (or percotherm). The hot water from the percotherm is used to preheat makeup air supplied to the facility as well as to preheat makeup water for a boiler feedwater system. Detailed energy use and performance data were collected at 15-minute intervals for nearly one year to quantify system performance. The unit's programmable controller was used to collect the monitored data. Sufficient data were collected to predict annual operating trends and extend the analysis to other locations around New York State. Utility rates were also used to extend the economic analysis from this site to other cities around the state. The results showed that the annual value of the recovered heat ranged from $4,500 to $8,000, which was much less than the expected savings. The modest savings occurred because of the unexpectedly light loads on the steam boiler. Parasitic electric use by pumps and fans, which increased costs by $1,800 annually, also diminished the net savings. This result illustrates the uncertainty with projecting production-driven loads on equipment in industrial settings. The cost effectiveness of these systems often depends strongly on future projections of energy use and production capacity.

Introduction

Heat recovery from industrial processes is a promising technology that can reduce energy use and improve profitability of commercial operations. This is certainly true for the bakery industry, where significant heat from baking ovens is exhausted to ambient air without being utilized for other processes. Potential uses for recovered heat include tempering of makeup air during the heating season and preheating feedwater for steam boilers (used in the proofing process).

One method for recovering heat from oven flue gases is to install a direct-contact heat exchanger. In these systems, flue gas is diverted through a special heat recovery stack. Water is sprayed into the top of the stack, where it falls through 3 to 4 feet of packing material and picks up heat from the rising stack gases. The heated water is collected at the bottom of the percotherm unit and is pumped through plate-and-frame heat exchangers that provide heat to loads in the facility. The cooled stack gases are exhausted through an exhaust stack atop the unit.

Keyspan Energy (formerly Brooklyn Union) and the New York State Energy Research and Development Authority (NYSERDA) teamed up to demonstrate and test this technology in a commercial bakery facility in Brooklyn, NY.

Project Objectives

The main objective of this project was to demonstrate, monitor and analyze the potential of direct-contact heat recovery technology in an industrial application. The specific project objectives were to:

- Quantify the amount of heat recovered to heat makeup air in the production area of the baking facility.
- Quantify the amount of heat recovered and used to preheat makeup water for two steam boilers.
- Determine the operating cost savings resulting from the recovered heat, factoring in the impact of the system's parasitic electric loads.
- Extend the heat recovery performance and cost savings of the system to other locations.

Site Description

The commercial bakery facility evaluated in this study is located in Brooklyn, New York. This large commercial bakery produces quality rolls, breads and bagels that are distributed throughout the Northeastern United States.

The facility contains several natural gas baking ovens, including three tunnel ovens, one brick oven, and two rack ovens (see Table 1). The rated gas consumption of all the ovens is more than 8 million Btu/h. The facility also includes two low-pressure steam boilers that produce steam for use in the baking process (proofing) as well as for other uses.

The direct-contact heat recovery unit was installed on the largest dual-burner tunnel oven. Flue products from this oven were previously exhausted through conventional stacks.

Table 1. Bakery Equipment Description

Component	Description
Baking Ovens	One (1) Tunnel-Flow Oven. Two Burners, 3.0 MMBtu/h total Two (2) Tunnel-Flow Ovens. Single Burner 1.5 MMBtu/h. One (1) Brick Oven. Single Burner 1.5 MMBtu/h. Two (2) Rack Ovens, One (1) Bagel Oven.
Low Pressure Steam Boiler	200 HP (nominal: 6.7 MMBtu/h, range: 2.51 to 8.37 MMBtu/h)
Backup Boiler	350 HP (nominal: 11.7 MMBtu/h)
Space Heating System	Several gas, direct-fired unit heaters

The direct-contact heat recovery system evaluated in this study is schematically shown in Figure 1, with component details listed in Table 2. The heart of the system is a stainless steel "percotherm" direct-contact heat exchanger. The added air-side pressure drop caused by the percotherm unit requires the use of a 3 HP induced draft fan to maintain proper exhaust flow, or draft, from the ovens.

Heat recovered in the percotherm unit is transferred to other loads through two stainless steel plate-and-frame heat exchangers. The first heat exchanger (HX1) is used to preheat makeup feedwater for the steam boiler. The second heat exchanger (HX2) is used to heat the glycol loop connected to a 10,000 cfm makeup air unit. Heated water is circulated from the percotherm unit to the heat exchangers by a 3 HP pump. The system includes a programmable logic controller (PLC) that controls its various functions. The percotherm water slowly becomes acidic as it recirculates and absorbs combustion products from the flue gases. Therefore, the percotherm water loop includes a purge cycle that periodically drains and replaces water from the percotherm to control acidity.

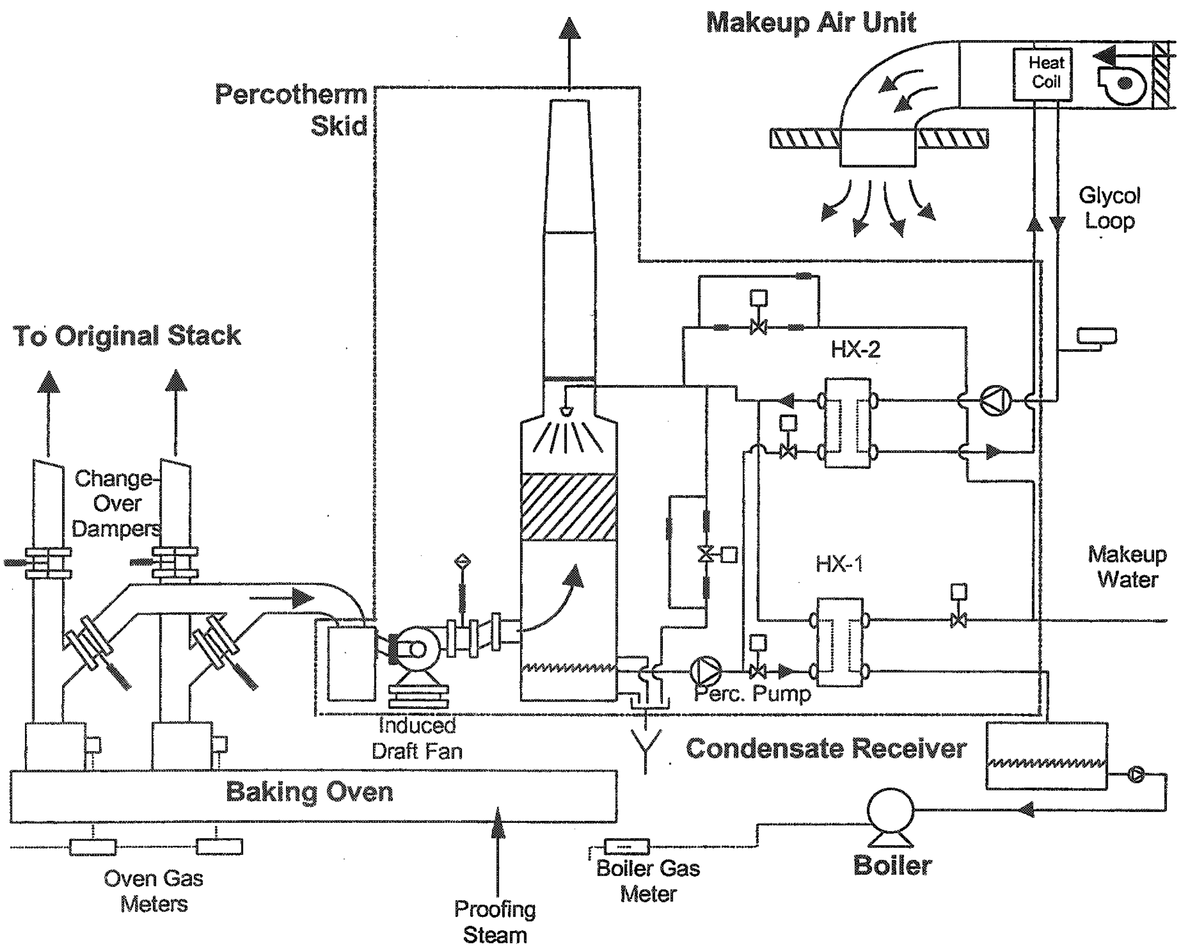

Figure 1. Schematic of Percotherm Heat Recovery System

Table 2. Percotherm Component Details

Component	Description
Percotherm Unit	Direct-contact heat exchanger with 3-4 feet of packing material. Stainless steel unit with 20 ft stainless steel stack.
Percotherm Water Pump	3 HP
Induced Draft Fan	3 HP fan rated (maintains –0.1 inches static)
ECP-1 / HX1	Model: Flow –30FT25-MD1ED (boiler feed water)
ECP-2 / HX2	Model: Flow – 30FT50-MD1ED (makeup air glycol loop)
Glycol Loop Pump	1.5 HP
Makeup Air Handler	7.5 HP, 10,000 cfm

Monitoring Procedure

A total of 31 data points were monitored and collected by the programmable controller. These measured points, recorded at 15 minute and 1 minute intervals, provided a thorough characterization of system performance. The continuously monitored data points included temperatures, water flow rates, levels, gas use, and component runtime/status. One-time readings were also taken of electricity use of the pumps and fans in the system, in order to quantify the parasitic energy use. Data were collected during the period from June 1999 to July 2000.

An on-site personal computer (PC) that serves as the operator interface to the percotherm PLC was also used for data collection on that system. The PC software was configured to write all data to a set of files, which were archived at the end of each day. The data consist of instantaneous readings of the analog and status points as well as totalized readings for the pulse output devices (i.e., gas meters).

Results and Discussion

System Operation

The heat recovery system operated sporadically during the test period due to several technical problems with the unit. The problems were in some cases due to the particular characteristics at this site and in other cases the heat recovery unit itself. The site difficulties included environmental temperatures over 110°F, which caused faults in the onboard control system. Poor construction of the field installed glycol loop piping between the skid and the makeup air handler also resulted in leaks and limited operation of the makeup air heat recovery system. Issues with the heat recovery unit itself included corrosion of the galvanized spray nozzles that degraded system performance within the first year (until they were replaced with stainless steel components). In some periods instrumentation failed or malfunctioned, which also limited the usefulness of the data for the period. Accurately measured and stable operation of the unit occurred only during three periods, for a total of 52 days of operation. These periods are listed in Table 4.

Table 4. Summary of Periods of Good Operational Data

Dates of operation (days)	Length of period	Heat Exchangers in service during period
September 14 – October 4, 1999	21	HX#1
January 31 – February 15, 2000	16	HX#1, HX#2
June 19 – July 3, 2000	15	HX#1

Note: HX#1 = boiler feedwater loop, HX#2 = makeup air glycol loop

Boiler and Energy Use Profiles

Gas use by the ovens and the boilers over the course of the entire study is shown in the daily load profile plots of Figures 2 through 4. Generally the ovens operated from 8 am until 10 pm, or 14 hours per day, though on some days they remained on overnight. Boiler operation tended to run longer than the ovens, staying on until about 4 am. Average daytime gas use of the boiler was about 2.5 MMBtu/h, which is much lower than its rated nominal capacity of 6.5 MMBtu/h. Boiler consumption never exceeded 3.5 million Btu/h.

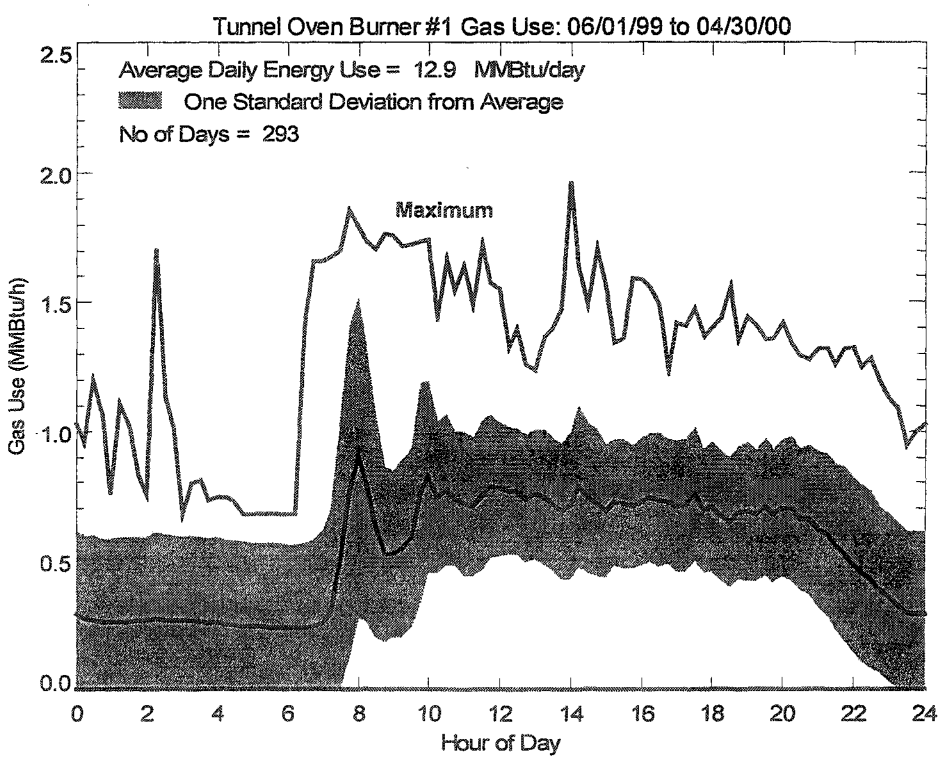

Figure 2. Profile Plot of Oven Burner #1 Gas Use

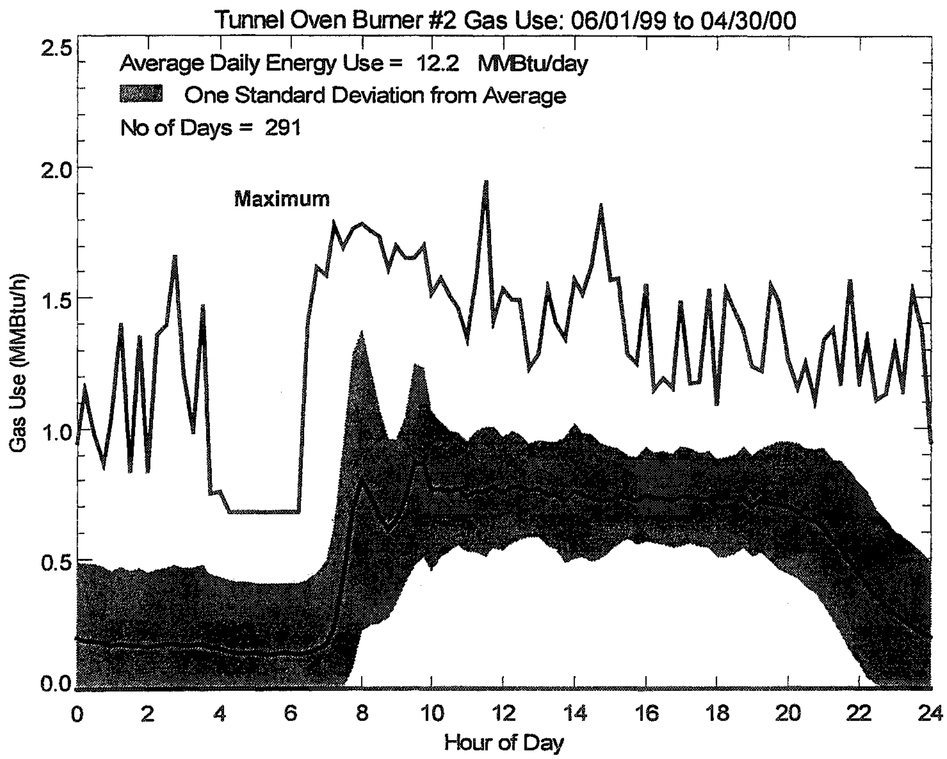

Figure 3. Profile Plot of Oven Burner #2 Gas Use

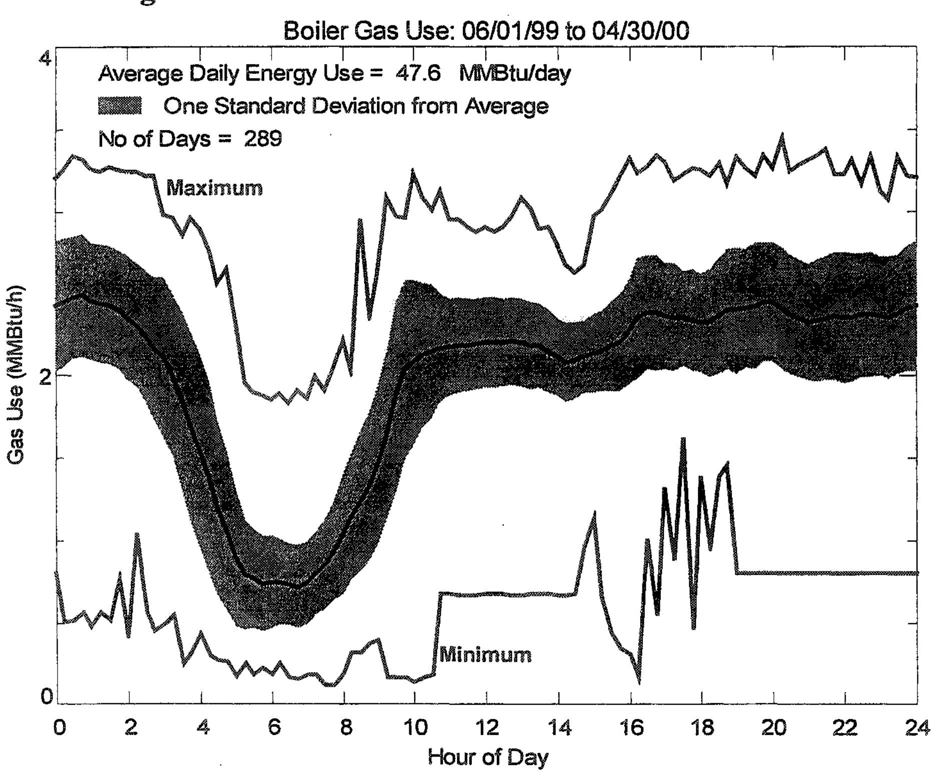

Figure 4. Profile Plot of Boiler Gas Use

Typical System Operating Patterns

Typical operation of the Sofame unit is presented in Figure 5 in the form of a "performance snapshot" of system performance over a 2 day period. This graph shows the daily trend of various temperatures and equipment operating status and is useful for understanding the daily operating cycle of the system. Figure 5 shows a performance snapshot for the Percotherm system on June 20 and 21, 2000.

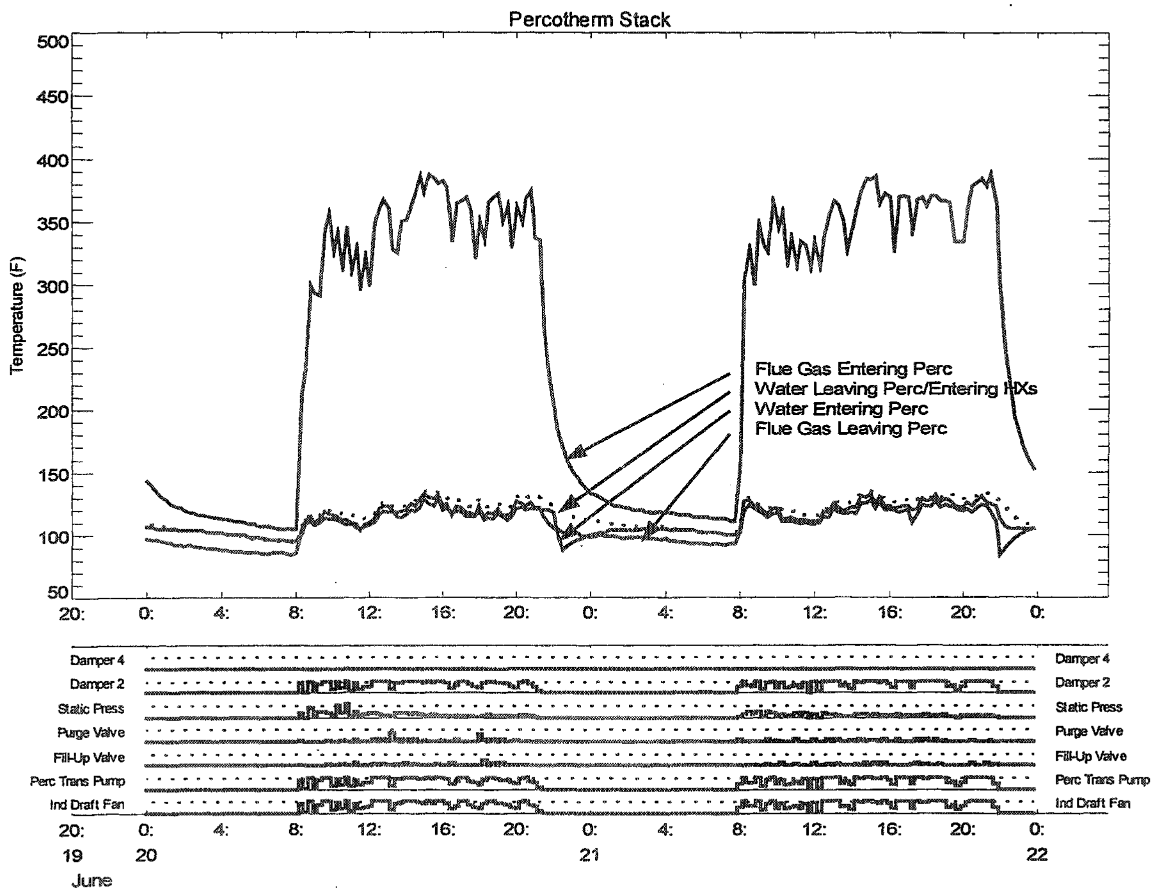

Figure 5. Performance Snapshot of Percotherm Stack.

The temperature of the flue gas entering the percotherm is approximately 345 °F while the ovens are on (from 8 am until about 10 pm). The temperature of the flue gas drops to about 120 °F as it rises through the percotherm, because the percotherm water is removing heat from (or cooling) the flue gas. Water leaving the percotherm unit for the heat exchangers is approximately 125° F, and the return water back to the unit is about 116°F. The corresponding heat transfer from the percotherm system on this day was 63,000 Btu/h (with no makeup air heating taking place). The ovens and the percotherm are off during the period from midnight to 8 am, and temperatures slowly trend towards the ambient air temperature during that time.

Overall Performance Trends

The amount of heat recovered daily by the system is plotted as a function of outdoor air temperature in Figure 6. The trend of daily heat recovery versus ambient temperature can be used with annual weather data to predict the annual performance of the system. This allows economic analysis of the system with weather data for multiple locations.

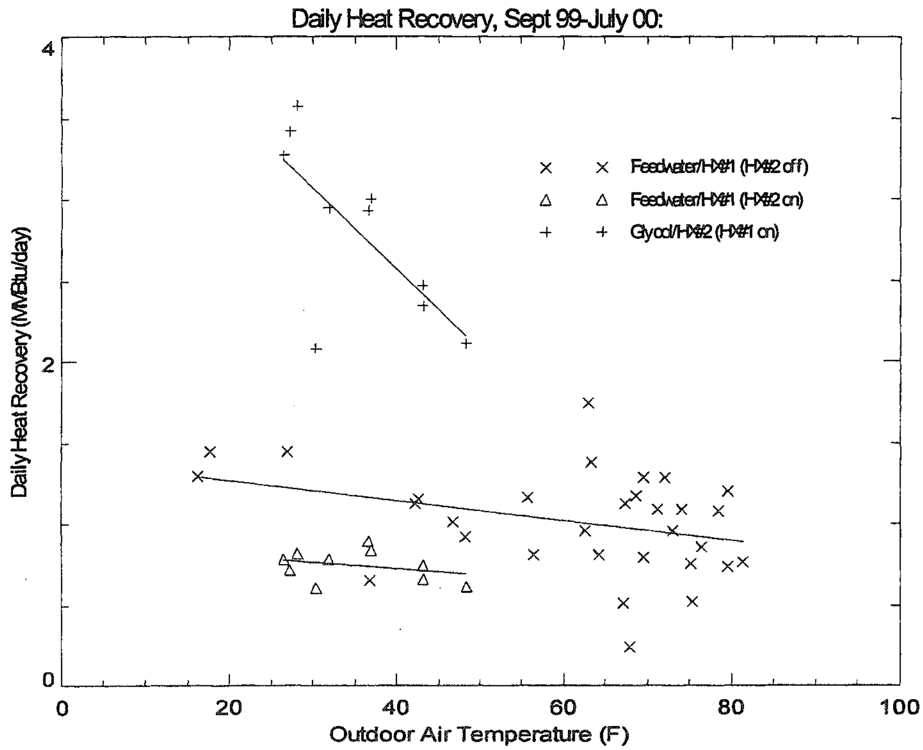

Figure 6. Daily Heat Recovery from the Percotherm System vs. Outdoor Air Temperature.

A regression analysis of the heat recovery trends in Figure 6 results in the following linear models:

Feedwater HX1:

$Qhx1 = 1.38 - 0.00542 * OAT$ (when HX2 is off; summer)

$Qhx1 = 0.886 - 0.0039 * OAT$ (when HX2 is on; winter)

Glycol HX2:

$Qhx2 = 4.56 - 0.0494 * OAT$

The makeup air heat load (HX2) varies with ambient temperature because the system is controlled to maintain a supply air setpoint of 70°F and only operates at ambient temperatures below 52°F. The feedwater heat exchanger load (HX#1) is analyzed for two conditions: with and without the glycol loop operating to heat makeup air.

When the glycol loop is off, all the heat from the percotherm unit can be used to preheat the feedwater, and the heat transfer to that system is higher. The amount of heat recovery increases slightly at lower ambient temperatures, because the lower entering city water temperatures during winter months provides more potential for heat transfer.

Economic Analysis

The total savings from the heat recovery unit was estimated using the linear regression models from Figure 6 and typical meteorological year (TMY) data for LaGuardia Airport. The predicted annual savings are given in Table 5. The predicted savings implicitly assume that the system functions as shown in Figure 6 for each day of the week. Makeup air heating is only assumed to be required when the average daily temperature drops below 52°F. The boiler preheat energy savings jump to the higher model (i.e., with HX2 off) when space heating is not required. With these assumptions, the system recovers about 765 MMBtu annually, and eliminates almost 9,600 therms/year of gas use. Gas savings can be attributed to both reduced unit heater and boiler consumption. With the interruptible rate used at the site projected to 2001, the annual gas savings are $6,318.

Table 5. Projected Annual Savings from Heat Recovery

	Heat Recovered (MMBtu)	Gas Use Displaced (therms)	Cost Savings
Makeup air heating	441.3	5,516	$ 3,641
Boiler feedwater heating	324.6	4,058	$ 2,677
Total heating	765.9	9,574	$ 6,318

Assumptions: Boiler efficiency = 80%,
Gas savings based on Brooklyn Union's 6C2 "interruptible" rate projected to 2001 ($0.66/therm)

The heat recovery unit also has pumps and motors that consume electricity. Electricity rates were based on Consolidated Edison rate SC 9.1 with the middle block used for energy costs (based on the assumption that other electrical loads in the facility would push usage into that block). Table 6 shows that these parasitic loads increase operating costs by $1,857, reducing the net savings to about $ 4,462 per year. This corresponds to a simple payback period over 20 years, assuming a purchase & installation cost of $100,000 for the system.

Table 6. Annual Parasitic Energy and Costs

	Power (kW)	Runtime (hrs/day)	(days/yr)	Energy Use (kWh)	Cost
Induced draft fan	1.05	14	365	5,366	$645
Percotherm pump	1.41	14	365	7,205	$866
Glycol pump	1.36	14	165	3,142	$345
Total				15,713	$1,857

Assumptions: Power use based on one-time measurements,
Costs based on Consolidated Edison schedule S.C. 9.1 ($0.118/kWh average)

The annual savings of $4,462 were lower than the originally-anticipated annual savings for this facility. The original savings prediction was based on a number of assumptions about system operation that do not agree with the actual measured and observed data. These original assumptions are compared to observed performance in Table 7.

Table 7. Comparison of Original Operational Assumptions to Measured Performance

Description	Original Assumption	Measured / Observed
Percotherm flue gas temperature drop (°F)	400	198
Boiler water use rate (gal/day)	17,600	4,000
Feedwater Heating (MMBtu)	3,213	441
Oven (or Percotherm) runtime (hrs/day)	22	14
Electricity cost ($/kWh)	NA	0.049
Gas cost ($/therm)	0.60	0.66

The original estimates were that boiler feedwater heat recovery would save nearly $20,000 per year, and that makeup air heating would save another $5,000 to $10,000 annually. These savings estimates were based on two main assumptions that proved to be flawed:

- The boilers operate at full load most of the time
- The tunnel ovens operate nearly around the clock

The assumption about boiler loading proved to have the biggest impact. The boilers have, on average, operated at less than one third of the rated output (see Figure 4.) The shorter operating time of the ovens – and the corresponding reduction in the potential of heat recovery – combined with the lower output to reduce the cost savings by a factor of 4 to 6 compared to the original projections.

The economic analysis of the heat recovery unit was completed using weather data and utility rates from other cities in New York State to assess the cost effectiveness of the system under these other conditions. Local utility rates were used with TMY data for Albany, Buffalo, and Plattsburgh, NY. In addition, the analysis was repeated in Brooklyn with a non-interruptible gas rate (Brooklyn Union SC 2-1). The utility rates are summarized in Table 8.

Results of the economic analysis for each city are given in Table 9. When the normal, non-interruptible gas rate for Brooklyn is used, the net savings increase to $6,376. Annual savings in upstate cities are also higher because of both the higher cost of gas and the large space heating loads. Makeup air heating loads are 29% higher in both Albany and Buffalo and 46% higher in Plattsburgh. Overall, the weather in Plattsburgh resulted in net annual savings of nearly $8,000.

Table 8. Electricity and Gas Rates Used in Economic Analysis

	Electric Rate	Gas Rate
Brooklyn	Con Ed SC 9.1 ($18.68*/kW, $0.07064/kWh)	Brooklyn Union SC 6C2 *interruptible* ($0.65999/therm)
Brooklyn	Con Ed SC 9.1 ($18.68*/kW, $0.07064/kWh)	Brooklyn Union SC 2-1 ($0.85999/therm)
Albany	Niagara Mohawk SC3 ($14.97/kW, $0.0668/kWh)	Niagara Mohawk SC2 ($0.72198/therm)
Plattsburgh	NYSEG SC2 ($8.87/kW, $0.0570/kWh)	NYSEG SC2 ($0.76199/therm)
Buffalo	Niagara Mohawk SC3 ($14.97/kW, $0.0610/kWh)	National Fuels SC3 ($0.66199/therm)

Notes: Gas rates include commodity and delivery charges. Commodity charges based on projected costs for 2001. Commodity gas is assumed to be 2 cents cheaper downstate than upstate.
* - Con Ed rates vary for each month; annual average is shown.

Table 9. Annual Energy and Cost Savings for Other Sites

	Heat Recovered (MMBtu)	Gas Use Displaced (therms)	Heating Cost Savings	Parasitic Electric Costs	Net Savings
Brooklyn (interruptible):					
Makeup air heating	441	5,516	$ 3,641	$1,857	$ 4,462
Boiler feedwater heating	325	4,057	$ 2,678		
Brooklyn					
Makeup air heating	441	5,516	$ 4,744	$1,857	$ 6,376
Boiler feedwater heating	325	4,057	$ 3,489		
Albany:					
Makeup air heating	568	7,103	$ 5,128	$1,603	$ 6,438
Boiler feedwater heating	323	4,036	$ 2,914		
Plattsburgh:					
Makeup air heating	644	8,048	$6,132	$1,224	$ 7,965
Boiler feedwater heating	321	4,011	$3,056		
Buffalo:					
Makeup air heating	571	7,131	$ 4,721	$1,513	$ 5,867
Boiler feedwater heating	321	4,017	$ 2,659		

Lessons

The experiences from this study demonstrate the importance and difficulty of accurately quantifying the actual loads on equipment as part of the initial feasibility analysis. When the equipment was selected in 1994, the steam boiler was expected to be fully loaded based on the plans for additional baking ovens and increased production. In reality, the data collected in 2000 showed that the boiler was about one third loaded and the ovens ran for fewer hours of the day than had originally been anticipated (so heat recovery was possible for fewer hours). These two factors drastically reduced the energy savings by a factor of 4 to 6. The cost effectiveness of the system was proportionally impacted.

Acknowledgements

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