Potential For Savings Using a Gas Booster Heater in Commercial Dishwashing Applications

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Sanitation standards require that restaurants and institutions with high-temp commercial dishwashing equipment must sterilize dishes in water that is at least 180°F. Typically, a booster heater is used to raise the temperature of the water coming from the service water heater to the required temperature. Booster heaters generally use electric resistance immersion elements to heat the water, but gas booster heaters have recently become available. Given the generation and transmission losses inherent in electrical power, gas booster heaters could be expected to use less total energy than electric units. They might also help to reduce utility system peaks and environmental impacts. If the facility is in an electric rate class which includes demand charges, and if the heaviest use occurs when the building is experiencing its overall maximum use, using a gas booster heater rather than electric can represent a substantial cost savings to the restaurant owner.

The impact of booster heaters on several businesses' electric bills was evaluated, along with the savings associated with using gas booster heaters. Electric load monitoring equipment was installed in five restaurants and institutions over a six month period. In addition, data from two restaurants involved in a previous study were analyzed. In three of the seven restaurants the booster heater made a significant contribution to the overall building electrical demand. In these cases, with a low electric rate, the paybacks on the installed cost of using a gas booster heater were between 0.8 and 6.0 years depending on the model of gas booster heater selected.

Introduction

Washing dishes is an essential component of a restaurant's operations. It can also be an energy-intensive process, and therefore has the potential to be a major expense. In order to comply with National Sanitation Foundation (NSF) Standard 3-82, dishes must be sanitized during every wash cycle. There are basically two means of accomplishing this. One is to use a hot water rinse (high-temp), and the other is to use a chemical rinse (low-temp). This study looked at one way to reduce the cost of commercial dishwashing while still providing the same quality of cleansing.

We targeted restaurants and institutions using dishwashers with electric booster heaters, and assessed the economics of converting to gas booster heaters. The heater typically boosts the temperature of the water coming from the restaurant's service water heater from 140° - 150°F to 180° - 190°F during the final rinse. The surface temperature of the dishes and utensils must be raised to at least 160°F in order to destroy any pathogenic bacteria, which takes about 9 seconds for most commercial dish machines using 180°F water. The majority of booster heaters being used today are electric units with immersion elements which heat the water in a small storage tank and maintain it at the aquastat setting. Different sizes of commercial dishwashers require booster heater inputs ranging from 7 kW to 54 kW. Given their large inputs, booster heaters can have a large effect on the businesses' electric demand if they are peak coincident, as well as on electric energy use. The recent availability of compact gas booster heaters could provide an opportunity for significant operating cost savings.

This project collected and analyzed metered end-use data to determine whether switching from electric to gas booster heaters would be cost-effective in typical applications. Some cost savings can be realized because natural gas is generally cheaper than electricity ($0.50/therm for gas in the study area, $0.03/kWh for demand-billed commercial customers), even when the difference in on-site efficiency of electric and gas booster heaters is taken into account. But the major opportunity for cost savings comes from reducing the businesses' peak demand, since monthly demand charges are typically a large part of commercial customers' electric costs (average $6.50/kW in the study area). Thus the major factors in the economics of conversion are the actual booster heater draw and the coincidence between booster heater demand

and the customer's overall monthly peak demand, which determines their billing charges. To assess these factors, booster heater and total demand were monitored continuously at a number of restaurants and institutions in 1990, under funding from the gas utility. The complete results of the study can be found in Sachi et al. (1990).

Background

Based on previous studies, of the approximately 500,000 food service establishments in the U.S., 200,000 or 40% require dish sanitizing devices (Liljenberg 1987a). Recent data suggest that the total has grown to 619,000 food service establishments, and therefore 250,000 that require sanitizing devices (Duga 1988). Foodservice Equipment & Supplies Specialist Magazine publishes annual sales figures for the various types of dish machines, which show that from 1985 to 1989, high-temp dish machine sales accounted for 60 to 64% of the dish machine market. Seventy percent of high-temperature (180°F) commercial dishwashing machines use electric booster heaters (Liljenberg 1987b); the other 30% use gas booster heaters or generate hot water from the building's steam distribution system. Liljenberg's study (1987b) also found through surveys that an increase in the availability of gas-fired booster heaters would be welcomed by the food service industry.

The most common types of commercial dish machines are single-rack door-type dishwashers (85% of the market) and automatic-rack conveyor-type dishwashers (15% of the market). When high-temp sterilization is used, the former most commonly use 15 - 18 kW electric booster heaters and the latter 36 - 45 kW booster heaters.

Test Buildings

The objective of the study was to monitor a sample of typical facilities with booster heaters of the most common sizes. The buildings were all restaurants with the exception of one which was a health care facility, and the electric booster heaters ranged in size from 7 to 45 kW (Table 1). The buildings monitored were located in the Minneapolis/St. Paul Metro Area. Data collected in two additional buildings by Penn State University and Pacific Northwest Laboratory for a study by the U.S. Department of Energy (Claar et al 1985) were obtained and analyzed to supplement the local data set.

The buildings chosen all had dish machines that were in good working order when the monitoring started. The buildings were instructed to operate in a "business as usual" mode, so that the normal energy use patterns of the site would not be affected by the monitoring.

***Table 1.** Site and Equipment Information*

Site #	Type of Facility	Total Area	Dishmachine Type	Booster Htr Size (kW)
1	Restaurant & Pizzeria	1,800	Single Rack Door Type	15
2	Bakery & Restaurant	3,600	Single Rack Door Type	7
3	Halfway House	1,500	Single Rack Door Type	18
4	Restaurant	2,700	Single Rack Door Type	17.25
5	Restaurant & Bar	9,500	Conveyor Type	45
6[a]	Pizzeria	2,200	Single Rack Door Type	18
7[a]	Restaurant	6,700	Conveyor Type	45

(a) Data received from Pacific Northwest Laboratories.

Experimental Design and Analysis

In order to determine the coincidence of booster heater usage with the business's overall electrical peak, it was necessary to monitor the total electrical load of the business along with the electrical draw of the booster heater.

Five minute averages of booster heater and building electrical use as well as percent dishwasher runtime were recorded. The local electric utility bases its demand charge on the highest fifteen minutes of demand during the billing period, determined using a sliding window. The five minute averages collected were transformed into sliding fifteen minute averages. These averages could be offset from the utility's peak window by at most 2.5 minutes, which was felt to be an acceptable error, balancing accuracy against the cost of storing more, shorter averages and downloading data more frequently. The data from Claar et al were only available in fifteen minute average form.

The electric use data for each site were plotted versus time and the maximum building load from the data period with and without the booster heater use included was determined. The difference between the maximum building electric peak including the booster heater use and the maximum building peak without the booster heater included is the billable demand savings achieved by eliminating the electric booster heater.

Four to eight weeks of data were analyzed for each Minneapolis site, in order to be certain to obtain the same peak electrical load used in billing. The data from Claar et al. included a year of electric use, but only three months could be analyzed for each site due to incomplete and/or corrupted data. An important objective of the study was to be able to use the results of the short-term monitoring to estimate yearly savings that could be achieved by converting to a gas booster heater. In examining electric bills from the previous year, it became apparent that the demand peaks were quite variable from month to month, with coefficients of variation (standard deviation/mean) for each site ranging from 12 to 15%. Much of the variation appeared to be caused by the air conditioning systems, so a more detailed analysis of electric use was performed on the data from Claar et al to evaluate the contribution of the booster heater to the total building electric demand with and without the air conditioning usage. These data covered both summer and fall months and had each electric load monitored separately, so that it was relatively easy to analyze the booster heater impact with and without the air conditioning load, using data from different months and also summer data with and without the air conditioning load included.

The analysis did not reveal any strong seasonal effect (Appendix A), thus, the average impact of the booster heater on billed demand over a full year can reasonably be estimated from the short term data collected. For the Minneapolis cases with only four weeks of data available, the difference in the maximum demand observed with and without the booster heater load during the entire monitoring period was used directly. For cases with more than four weeks of data, the data were divided into overlapping four week periods, offset by one week, and the average of the impact determined separately for each four week period was used. For the Claar et al. data, the demand impact was determined separately for each month of data available and then averaged.

The energy cost savings that could be realized by switching from electric to gas booster heaters were estimated based on the average daily energy use of the electric booster heaters, the estimated difference in efficiency between electric and gas units, and the difference between electric and gas fuel costs. Average daily electric use was determined by multiplying average weekday, Saturday and Sunday use during the data period by the annual number of weekdays, Saturdays and Sundays that the business is open and dividing by the total days open per year. We estimated gas use in two different ways. The first was based on the electric use multiplied by a fuel equivalency factor commonly used when comparing electric and gas cooking equipment (Duga, 1987) and the second was based on the steady-state efficiency of the gas booster heater. The fuel equivalency factor of 1.8 in effect assumes an overall efficiency of 56% for the gas heater. The second method uses the NSF estimate of the steady-state efficiency of the gas booster heater, which from product literature is 75%. The electric costs used in evaluating the economics are low: the local electric utility has rates which are 135th among 167 utilities ranked by *Energy User News* (April 1992).

The performance of the gas booster heaters in providing the required volume of hot water at the specified temperature rise was evaluated in two separate performance tests, one completed by the gas utility, and the other by the authors. Both heaters were made by the same manufacturer, and had rated inputs of 125,000 Btu/h. The heater monitored by the gas utility was part of a prepackaged, patented assembly, with a five gallon storage tank and circulation pump. The gas utility test used two, three and four minutes between cycles to approximate the time typically required to load the dishwasher. The data included wash, rinse, and return temperatures, gas use and total Btu output. The piping between the booster heater storage tank and the dish machine was fairly extensive and was uninsulated, so that the piping losses were significant. Engineers at the gas utility estimated at least a 6°F temperature drop between the storage tank and the dish machine depending on the length of the off-cycle of the dish machine. As the off-cycle time increased, the temperature drop became larger, up to 23°F.

The authors used a system assembled by a local manufacturer's representative, which contained the same gas heater with a 20 gallon storage tank, and a circulation pump. The system was tested under the maximum requirements of a single-rack tank-type dishwasher. From manufacturer's data, the dishwasher used to determine flow requirements could run one rack per minute, with a nine second rinse using 1.21 gallons at 10 gpm. We allowed the heater to heat up to temperature, and then drew off the specified amount of water once every minute over a period of twenty-five minutes. We monitored the temperature of the water with a digital thermometer to be certain that it did not fall below the required forty degree rise.

Results

The data show interesting and widely varied results. Table 2 shows the rated load for the booster heater at each site, the maximum booster heater draw recorded, and the estimated average contribution to the overall electrical peak for the site. The average maximum electrical draw in a 15 minute period for the booster heaters ranged from 55% to 94% of the booster heater rated demand, and the average booster heater contribution to the overall building electrical peak ranged from 10% to 67% of booster heater rated demand. These figures indicate considerably lower potential for demand savings than one would estimate based on the rated load of the heaters.

The second half of Table 2 shows the gas use predicted by each method for each site. The two methods differ by 30 percent. Projected annual cost savings (demand plus energy) ranged from $150 to $2,300/yr applying the fuel equivalency factor to the kWh use; and from $225 to $2,500/yr using the estimated gas booster efficiency. Note that the savings are not particularly sensitive to gas booster heater efficiency, since most of the savings are from reduced demand charges. This is especially true for the sites where high booster heater demand is coincident with overall peak demand. It is the opinion of the authors that the method which calculates gas use based on the efficiency of the heater is more realistic than the method using the fuel equivalency factor, since the 56% overall efficiency implicit in the latter is considered to be too low for a booster heater with a small thermal mass and small off-cycle losses. Therefore the savings calculated using the steady-state efficiency were used to calculate paybacks.

The two most common gas booster replacements are a pre-packaged system and a system built-up with separate components. The installed cost for a small (125,000 Btu/h) pre-packaged system is $4,000 (Table 3), yielding a simple payback of 4.4 to 6.0 years at the sites where high booster heater and overall peak demand are coincident (Sites 1 and 6). A built-up system is cheaper than the pre-packaged unit, with installed costs of approximately $1,600. This results in more attractive paybacks of 1.8 to 2.4 years at the demand-coincident sites. A pre-packaged booster heater for the sites having 45 KW electric booster heaters costs approximately $5,300. For the large site with coincident demand, the payback would be 2.1 years. Using a built-up system with an installed cost of $2,100, the payback would be only 0.8 years. The paybacks associated with the built-up systems are in the range that restaurant owners would accept for the demand coincident sites. Even without coincident peaks, the payback for a built-up booster heater on the other large dishmachine (Site 7) would be 2.3 years (Table 4). These paybacks are based on a retrofit application. If one considers the possibility of using a gas booster heater in a new installation, the paybacks become more attractive.

Table 2. Summary of Electric Use Monitoring

Site #	Elec Booster Rated Power (kW)	Booster 15 min Max Draw (kW)	Percent of Rated Power	Bldg 15 min Max Draw (w/Bstr) (kW)	Average Booster Contribution to Monthly Bldg Peak (kW)	Average Contribution to Peak as % of Booster Rated Power	Estimated Yearly Elec Bstr Demand Cost[(a)]	Estimated Yearly Elec Bstr Energy Cost	Total Business Annual Electric Cost	Estimated Booster Heater Gas Use (1)[(b)]	Estimated Booster Heater Gas Use (2)[(b)]	Gas Booster Conversion Savings (1)	Gas Booster Conversion Savings (2)
1	15	14.2	94.5	45.0	7.51 (17%)	50.1	$572	$357	$7,838	724 Thms, $351	536 Thms, $260	$578	$669
2	7	4.9	70.1	70.7	4.46 (6%)	63.7	$340	$425	$12,945	861 Thms, $418	638 Thms, $309	$347	$455
3	18	9.9	54.7	50.3	1.88 (4%	10.4	$143	$293	$13,441	594 Thms, $288	440 Thms, $214	$148	$223
4	17.25	14.6	84.8	30.7	2.96 (10%)	17.2	$226	$167	$12,189	339 Thms, $165	251 Thms, $122	$228	$271
5	45	37.7	83.7	149.5	30.4 (20%)	67.6	$2,316	$709	$24,257	1,438 Thms, $697	1,065 Thms, $517	$2,328	$2,509
6[(c)]	18	15.5	86.1	100.6	10.57 (10%)	58.7	$805	$364	$31,500	737 Thms, $358	546 Thms, $265	$811	$904
7[(c)]	45	30.5	67.8	240.1	8.77 (4%)	19.5	$668	$853	$19,707	1,731 Thms, $839	1,282 Thms, $622	$662	$900

(a) Demand effect calculated from average of max draw w/booster minus max draw w/o booster, multiplied by average annual demand charge of $76.20/kw.

(b) Estimated booster heater gas use calculated two ways: (1) Average kwh use "conversion factor" 1.8 energy equivalency factor. (2) Average kwh "conversion factor/0.75 gas booster heater efficiency.

(c) Data for these sites was obtained from Pacific Northwest Laboratories.

Table 3. Gas Booster Heater Costs

System Options	Heater Input (Btu/hr)	Storage Capacity (gal)	Cost ($)
Pre-Packaged			
Heater w/accumulator	125,000	12	$3,100
Circulator option			299
Quick assembly option			225
Installation			375
Total			3,999
Heater w/accumulator	250,000	12	4,400
Circulator option			299
Quick assembly option			225
Installation			375
Total			5,299
Built-up			
Heater	125,000		500
Pump			185
Storage tank		20	150
Piping & Valves			150
Aquastat			100
Installation			500
Total			1,585
Heater	250,000		1,000
Pump			185
Storage tank		20	150
Piping & Valves			100
Aquastat			150
Installation			500
Total			2,085

Unfortunately, one can not simply look at the electric bills for a particular site or examine the type of booster heater and dishwasher in order to determine whether it will be a good candidate for a gas booster heater replacement. The electric use of the booster heater and building must be monitored to determine the correlation between high booster heater use and the business's overall demand in

Table 4. System Paybacks

Site #	Energy Cost Savings/Yr	Installation Cost[a]	Payback Range
1	$669	$1,600 - $4,000	2.4 - 6.0
2	$455	$1,600 - $4,000	3.5 - 8.8
3	$223	$1,600 - $4,000	7.2 - 17.9
4	$271	$1,600 - $4,000	5.9 - 14.8
5	$2,509	$2,100 - $5,300	0.8 - 2.1
6	$904	$1,600 - $4,000	1.8 - 4.4
7	$900	$2,100 - $5,300	2.3 - 5.9

(a) Installation costs include materials and labor, with material costs ranging from the lowest cost heater to the highest cost heater.

order to accurately estimate savings. A simple method for obtaining a rough estimate of savings potential is given in Appendix B.

Average booster heater load shapes over the monitoring period were plotted using data from the five sites the authors monitored and the two sets of data received from Pacific Northwest Laboratories. The load shape expresses the time of day the booster heater experiences its highest use and allows a comparison to be made between the booster heater peak and the electric utility's system peak. Figure 1 illustrates a load shape for one of the monitored sites.

A value of 1 for a particular hour indicates that at this time, the booster heater ran at the average load, while values above or below 1 indicate heavier or lighter use respectively. Peaks in the graphs indicate when the sites perform dishwashing and are also a potentially good indicator of when the sites see most of their customers. All the sites have distinct times of the day when the booster heater is under heavy use, and most sites have two such peaks, usually during and after the lunch and dinner rushes. During the peak booster heater consumption the booster heater draws 2 to 4 times its average load. The electric utility in the study area reaches its summer peak at approximately 1:00 pm and remains fairly flat until 3:00 pm and gradually declines until 6:00 pm, then falls off sharply. When the peak electric use of the booster heater is compared to the overall system peak

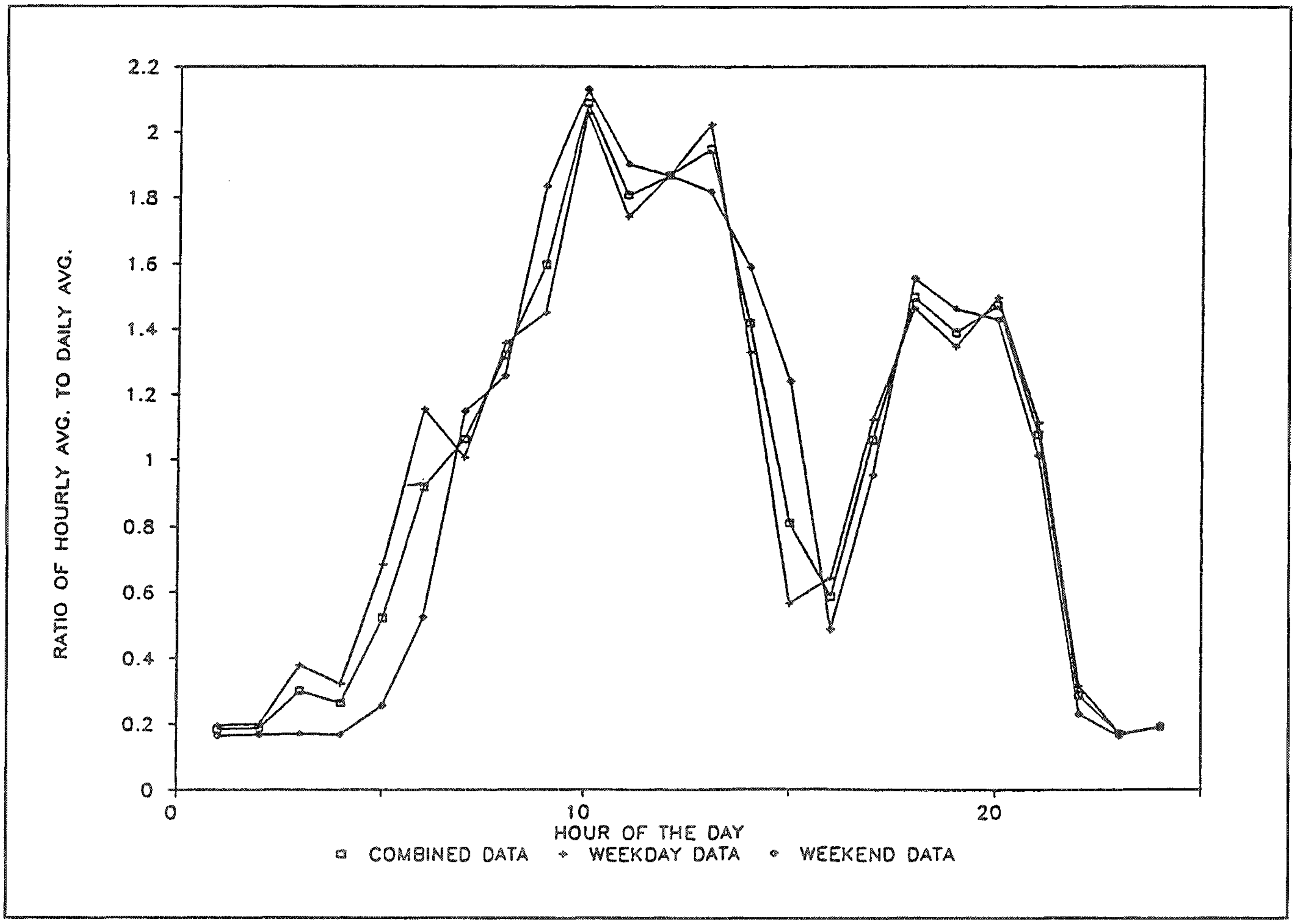

Figure 1. Average Booster Heater Load Shape (Site #2)

of the electric utility, it is evident that in many cases the peak booster heater use is indeed coincident with the electric utility's system peak.

The overall building electrical load also has a high use spike coincident with the utility's system peak. All of the sites monitored typically showed a heavy use period during the weekday afternoon hours, where the building was using 2 to 3 times its average electrical load. If the losses inherent in the delivery of both natural gas and electricity to the building are taken into account, it becomes apparent that an even greater difference in source efficiency exists between the two fuels. The cumulative delivery efficiency of coal-based electricity is approximately 29.1%, versus 91.2% for natural gas (AGA 1990). Using these numbers to calculate source efficiency yields 68.4% and 28.5% for the gas and electric bosster heaters respectively. This shows the gas booster heater option of being almost 2.5 times more efficient than the electric booster heater.

Gas Booster Heater Equipment Options and Performance

All commercial dishwashing booster heater sizing is based on the hot water requirements of the dishwasher rinse cycle. Rinsewater flow requirements are based on NSF listings, usually using a final rinse nozzle pressure of 20 psig. Booster heater sizing charts typically assume a 40°F temperature rise, since the inlet water is usually preheated to about 140°F by the building's service hot water heater.

Table 5 compares the inputs of the electric and gas booster heaters and the output based on a 40°F temperature rise, and assumed efficiencies of 98% and 75%. A popular practice among equipment specifiers is to oversize the booster heater by 25 - 50% of the NSF recommendations (Liljenberg 1987b), either so that the booster heater will function properly if one of the heating elements

Table 5. Booster Heater kW and Btu/h Ratings for Selected gal/h

Electric Input (kW)	Gas Input (Btu/h)	Water Output at 40°F Rise (gal/h)
4	17,000	40
10	44,000	100
15	67,000	151
24	107,000	241
30	133,000	301
36	160,000	361
42	187,000	422
48	214,000	482
58.5	261,000	588
81	360,000	810

should burn out, or simply to provide a 'safety factor' to assure that the booster heater will meet the hot water requirements of the dishwasher.

Two gas booster heater options are available at this time. The first option consists of a pre-packaged unit which includes an instantaneous heater, storage tank, circulation pump, and all associated controls, valves, and piping for the system. This unit is quite expensive at $4,000 installed ($3,624 equipment and $375 labor), but it also includes everything necessary for the proper operation of the unit. One drawback to the system is that since every component is standardized, and only two sizes are available, it may be necessary to use a significantly oversized unit for a large number of dishwashers. This problem is addressed by the second available unit, which is a built-up system and can be customized for each application. The pump, storage tank and burners can be sized to accommodate a wide range of dishwasher capacity requirements. It is also significantly less costly than the pre-packaged unit, with an installed cost of $1,600.

Both types of units were evaluated on their performance, the results of the performance testing by the authors are shown in Table 6. The booster heater tested (125,000 Btu/h, 20 gal tank) performed quite well in the

Table 6. CEUE Gas Booster Heater Drawdown Test

Test #	Time (min)	Temp (F)	GBH Status	Test #	Time (min)	Temp (F)	GBH Status
1	00:06	120.6	OFF	13	12:00	VOID	ON
2	01:00	118.6	OFF	14	13:00	115.3	ON
3	02:00	115.9	ON	15	14:00	118.5	ON
4	03:00	116.1	ON	16	15:00	120.5	OFF
5	04:00	118.5	ON	17	16:00	117.3	OFF
6	05:00	120.9	OFF	18	17:00	116.4	ON
7	06:00	117.3	OFF	19	18:00	119.3	ON
8	07:00	114.9	ON	20	19:00	121.0	OFF
9	08:00	117.7	ON	21	20:00	117.5	OFF
10	09:00	120.6	OFF	22	21:00	114.7	ON
11	10:00	121.2	OFF	23	22:00	118.3	ON
12	11:00	117.9	OFF	24	23:00	121.1	OFF

Assume: rinse cycle lasts 9 seconds
(AM series) rinse consumption per cycle
= 8.04 gpm (@ 20 lbs pressure)
= 9.90 gpm (@ 25 lbs pressure)
racks per hour = 53
Pressure set for 10 gpm for these tests
Therefore,
gallons per rinse cycle = 1.21 (@ 20 lbs pressure)
gallons per rinse cycle = 1.49 (@ 25 lbs pressure)
@ 20 lbs: 1.21 gallons in 9 seconds every minute for 1 hour @ 180°F
@ 25 lbs: 1.49 gallons in 9 seconds every minute for 1 hour @ 180°F
Approx 1.2 gallons drawn off every minute for these tests.

40°F temperature rise. Based on these data, this gas booster heater could successfully replace an electric booster heater of at least 15 kW.

Details of the tests conducted by the gas utility were confidential. The water heater they tested was a pre-packaged system, which had a 125,000 Btu/h input and a five gallon storage tank. Based on their tests, the unit would have had a difficult time meeting the hot water load with the dishwasher (normally served by a 15 kW booster) running at full capacity. They felt that with a larger storage tank, and with the piping insulated, the heater would be able to keep up with the hot water demand. Incorporating a recirculation pump between the storage tank and the dishwasher could also have an effect on the temperature of the rinse water. The pump would continuously circulate water between the storage tank and the machine, and would prevent water in the pipes from cooling to below 180°F before reaching the dish machine.

In fact, NSF recommends recirculation of 180°F water for any installation where the dishwasher is more than 5 feet from the water heater. The engineers did not get a chance to test these options.

A solution to these problems would be to develop a compact gas booster heater that would be a direct replacement for the existing electric booster heater, and would have the same footprint as the electric booster. The American Gas Association (AGA) Laboratory is working with, a major manufacturer to develop a direct-replacement for electric booster heaters designed for larger conveyor-type machines (24 - 36 kW). They are planning to install a prototype in several businesses with a gas utility and monitor the performance of the unit.

Market Issues

A number of barriers limit the potential market for gas booster heaters in the study area. Based on our experience in looking for study participants, more restaurants in Minnesota may have converted to low-temp machines, or may use steam injection or gas boosters, than previously believed. Approval by the central corporate office would be required for many chain facilities that have electric boosters to convert. Owners are concerned about the size and venting requirements of gas heaters and are not generally enthusiastic about conversion. They also have very short payback criteria and limited capital. Gas boosters are substantially more expensive than electric units, which limits their appeal even in new facilities.

Some suggestions as to how to penetrate the market developed from the study, based on the concerns of the restaurant owners and operators. A major concern was the space requirements that gas booster heaters have. In restaurant kitchens, space is at a premium. The gas booster heater typically needs more space than an electric booster heater, since the heater and storage tank are separate from each other. In some cases, the heater can be mounted in an adjacent storage area and piped to the storage tank next to the dishwasher. Another option is to mount the heater above a ceiling and out of the way of kitchen staff. If significant piping runs are made though, the lines must be insulated to reduce losses from the burner to the storage tank.

Venting was also mentioned as a concern. The gas booster is most cost-effective if it can be vented through an existing exhaust hood mounted above the dishwasher. In most cases commercial dishwashers must have vent hoods to exhaust the vapors created by the dish machine. The gas booster heater can usually be vented out through the existing exhaust hood, though some local codes prevent this due to the possibility of the combustion gases condensing and falling on the dishes. Some sites do not have these exhaust hoods and extensive piping must be installed to properly vent the heater. In these instances, the gas booster is most cost-effective if the heater is installed on or next to an outside wall, to reduce the vent piping needed.

Conclusions

At current energy prices in the study area, substantial but variable operating ccost savings could be achieved by converting from electric to gas booster heaters. In five test sites, estimated savings ranged from $223 to $904/yr for the 7 - 18 kW heaters, while at two sites with 45 kW heaters, savings were estimated at $900 and $2,509.

Electrical demand savings constitute the majority of the benefit to the businesses from a conversion to gas booster heaters. At the sites where booster heater use was coincident with the overall electrical peak, paybacks ranged from 0.8 to 6.0 years. In the non-coincident sites, the paybacks were substantially longer, ranging from 3.5 up to 17.9 years.

Based on manufacturers' recommendations and our tests, existing 15 kW booster heaters would require a 67,000 Btu/h gas replacement, with a 20 gallon storage tank, while 45 kW booster heaters would require a 200,000 Btu/h replacement with a 20 gallon storage tank.

Currently, a pre-packaged system with heater, tank, pump, piping and controls is available, with installed costs of about $4,000 for the 125,000 Btu/h model and $5,300 for the 250,000 Btu/h model. AGA is currently working with a manufacturer to develop a compact in-line gas booster heater for the automatic conveyor machine market (180,000 - 250,000 Btu/h). Systems can also be built up from components using a conventional domestic water heater. Based on component prices and estimated installation times, an experienced installer could probably install these systems at a total cost of $1,600 for the 125,000 Btu/h or $2,100 for the 250,000 Btu/h. To insure adequate hot water, piping runs must be minimized, a recirculation pump must be supplied, and the units must be site-tested when the installation is complete.

Given the variable paybacks and owners' typical one to two year payback criteria, some monitoring would be necessary to identify good candidates for conversion. Based on our experience, two weeks of data in a non-shoulder period of the year would provide a reasonably accurate basis for estimating savings potential, but the costs and intrusiveness of this monitoring present problems for marketing. A simplified approach was developed to screen potential candidates (Appendix B).

AGA's efforts to develop a compact in-line booster appear to be addressing the key concerns of the food service industry. The new unit is designed for typical conveyor machines and has the same dimensions as the electric booster heater, and therefore can mount under the dish counter next to the dish machine, reducing piping costs. AGA will also be developing a smaller unit sized to meet the requirements of the single-door type machines. The current installed cost is projected to be slightly lower than the low cost scenario presented in this paper. Assuming that those design objectives are met, the paybacks should be short enough to encourage owners to examine applications of a gas-fired booster heater. This will be especially true where electric prices are substantially higher than the prices in the study area, which savings estimates were based upon.

The paybacks do depend heavily on which gas booster heater is installed. In the two options analyzed there is more than a two to one variation in price between gas heaters with identical inputs. This can be credited to the configuration of the system, and the fact that one is prepackaged or already assembled, and the built-up system can be customized to the particular application.

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Appendix A

Since we collected data primarily in the summer, one question that arose was how well our data represent the annual impact of the booster heater on billing demand.

The available data from Claar et al. (Table A.1) suggest that the booster heater contribution to the building peak may be higher in non-cooling months than in cooling months, ("BH effect w/AC") though there are too few data points to be definitive. This seems plausible, in that an erratic air conditioning load could increase the chances of a substantial building peak that is not coincident with the booster heater maximum draw.

To look at this further, we subtracted the air conditioning loads from the PNL data ("BH effect w/o AC") and looked at the resulting booster heater contribution to the building peak with the air conditioning excluded. This approximates the impact of the booster heater in a winter month for a site without electric space heating. The results (Table A.1) do not show any consistent increase in booster heater impact with the air conditioning load excluded.

For the Minneapolis sites, booster heater contribution to building weekly peak demand was plotted against average outdoor temperature for the week (Figure A.1) for the two sites that covered a substantial range of temperatures, though neither of these data sets extended into the cooling season. A weak but non-significant effect was observed. The span of values is no greater than that observed for the sites monitored under constant weather conditions (3,4, and 5). Daily data for site 1 (Figure A.2) show no observable decrease in contribution as temperatures increased from day 1 (March 11) to day 49 (April 28).

Given the weak and conflicting trends shown in these explorations, it appears reasonable to accept the values derived from our data periods as substantially representative of annual impacts.

Appendix B

We would like to be able to quickly and fairly accurately estimate cost savings possible from converting from an electric booster heater to a gas booster heater. The simplified process to assess potential savings at a specific site should start with a determination of the highest dishwashing use at the business during open hours. The dishwashing patterns of this highest use period should be simulated at the site for 15 minutes, and the runtime of the booster heater measured. The runtime multiplied by the booster heater rated electric draw will give the booster heater energy use at the busiest time. The second input required is an estimate of the percentage of this maximum observed booster heater draw that is contributed to the building peak. Our data show that a higher percentage of the typical booster heater peak draw will show up in the overall building load when the maximum booster heater draw represents a larger portion of the overall building load, with only one prominent outlier case (site #2, which has a relatively small booster heater that is run consistently at a high percentage of its rated load). Among simple models constrained to pass through the (0,0) and (100,100) points, the best empirical fit comes from a model relating average monthly percent of building peak (Y) to maximum observed booster heater draw as a percent of maximum building load (X) by:

$$Y = 1 - (1-X)^{4.63} \pm 0.131 \quad \text{B.1}$$

$$R^2 = 67.84\%, \ p < 0.05$$

Examining the billing data for the site will enable us to compute the booster heater maximum draw as a percent of the overall building load. Using Figure B.1 will allow us to estimate the booster heater contribution to the building load and calculate the cost savings from converting to a gas booster heater.

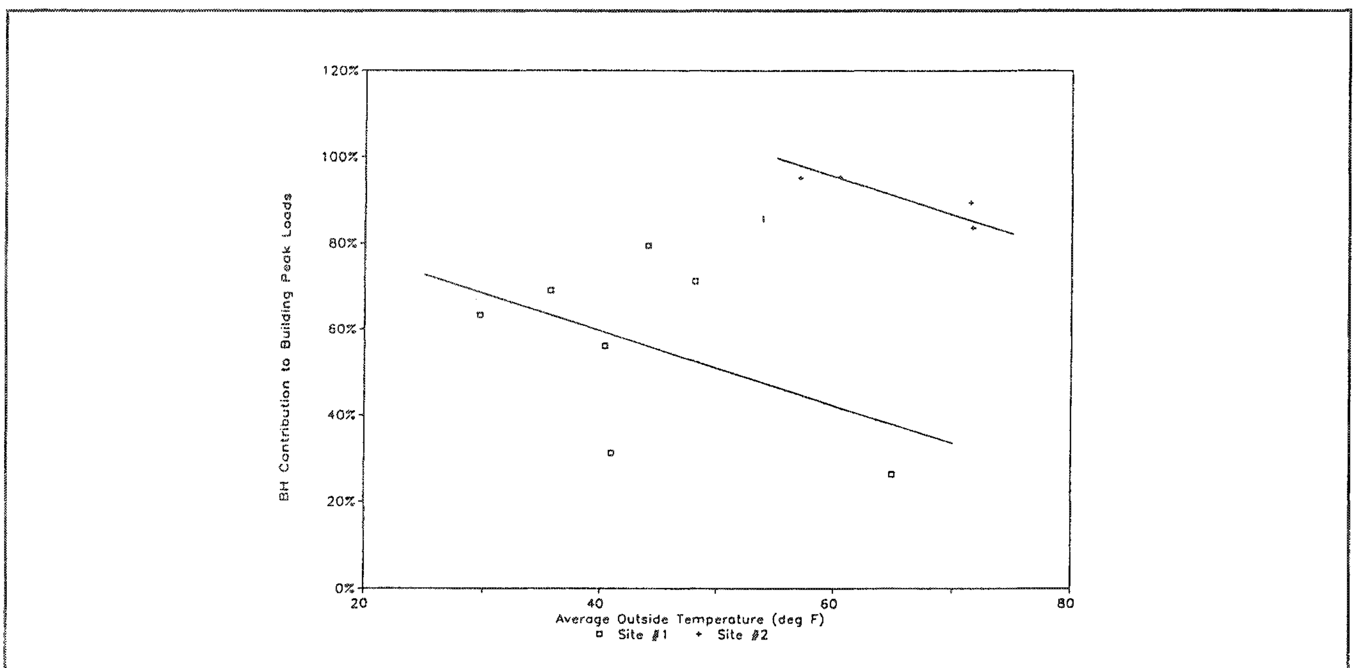

Figure A.1. Booster Htr Contribution to Bldg. Peak (Weekly Data)

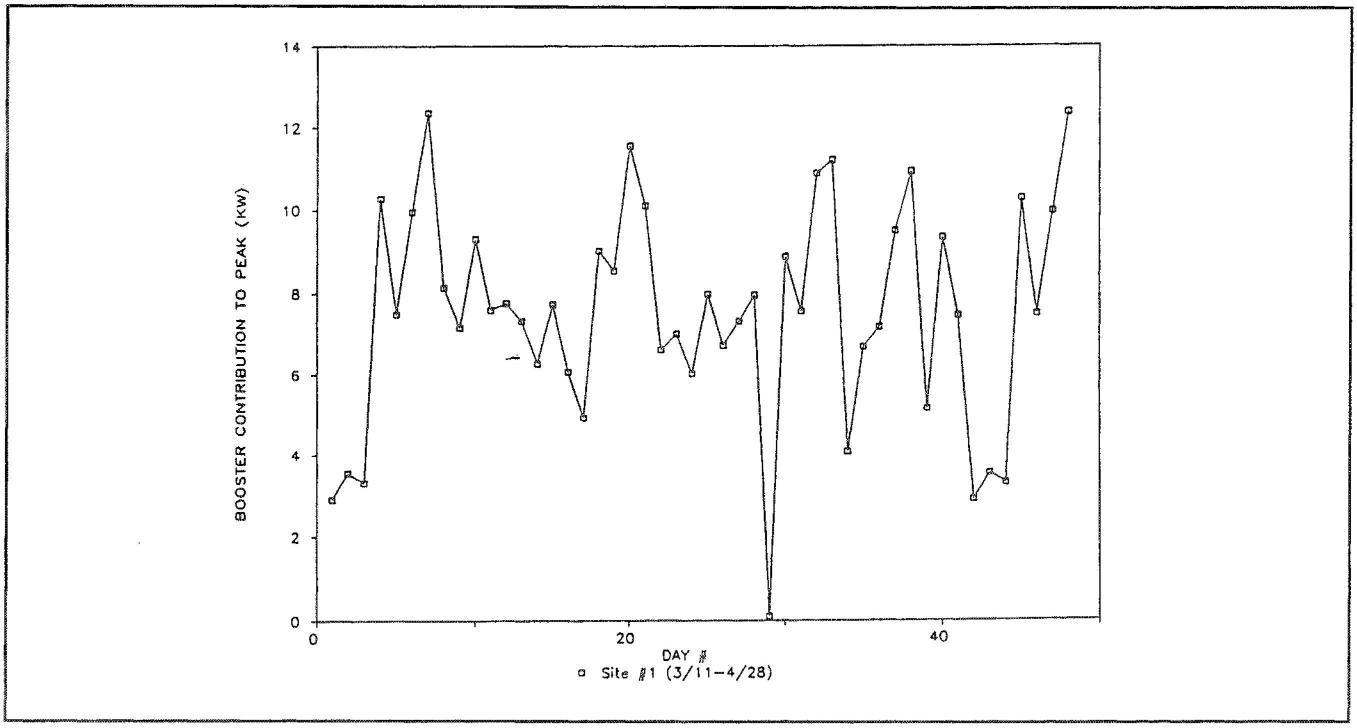

Figure A.2. Booster Htr Contribution to Bldg Peak (Daily Data)

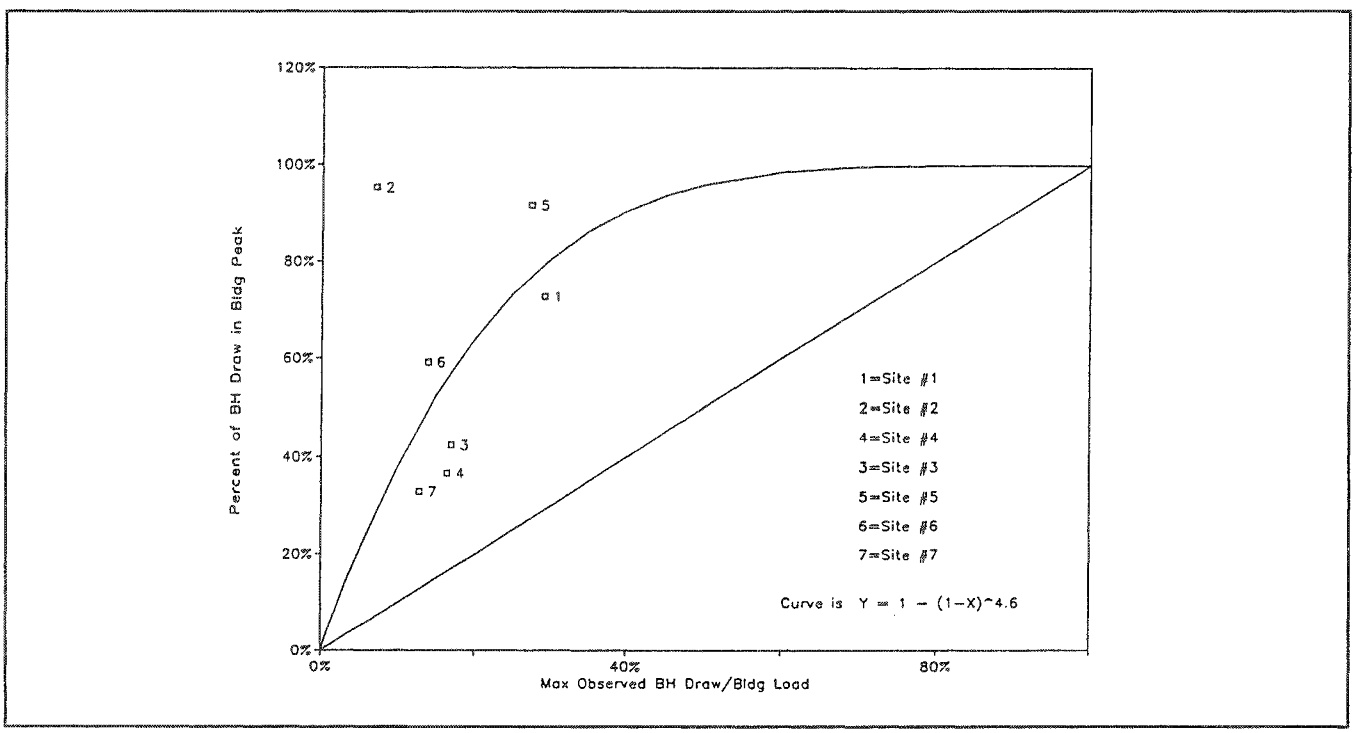

Figure B.1. Booster Htr Contribution to Bldg Peak (All Sites)