MEASURED SAVINGS FROM HIGH EFFICIENCY REPLACEMENT TANK-TYPE DOMESTIC HOT WATER HEATERS IN MULTIFAMILY BUILDINGS

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ABSTRACT

Domestic hot water (DHW) heating can account for almost 30% of the total energy use in apartment buildings, not counting the energy used for lighting and electric appliances. Perhaps the best opportunity for efficiency upgrades to DHW heating in multifamily buildings is at the time of equipment replacement. In order to measure savings and assess performance of the "best available technology" for this application, high efficiency condensing tank-type water heaters were installed in parallel with existing conventional tank-type DHW heaters in two apartment buildings. All tests were conducted using an alternating mode design monitored by a computerized data acquisition system.

Savings for the high efficiency replacement DHW heaters were about 28% of annual DHW consumption, corresponding to savings of 24 MBtu per year and 26 MBtu per year for the two cases investigated. Seasonal efficiencies of the condensing DHW heaters were measured at 78% and 81%. Comparable efficiencies for the standard DHW heaters were 56% and 58%.

Commercially available high efficiency tank-type water heaters are currently too small for larger buildings in which the DHW load (and therefore savings potential) can more readily justify the higher cost of this type of equipment to the owner. Paybacks found in this study were 19 to 20 years even when based on the incremental cost of using a high efficiency DHW heater over a conventional tank-type heater at the time of required heater replacement.

While one heater operated flawlessly throughout the test period, the other had problems with periodic failure of the igniter and tank leaks, indicating that this technology is not yet problem-free. This is a big deterrent for equipment intended for use in multifamily buildings since these owners are very sensitive to tenant complaints and are desirous of maintenance free mechanical equipment. As a result, development of more options for replacement DHW heating equipment for this sector seems warranted.

MEASURED SAVINGS FROM HIGH EFFICIENCY REPLACEMENT TANK-TYPE DOMESTIC HOT WATER HEATERS IN MULTIFAMILY BUILDINGS

INTRODUCTION

Domestic hot water (DHW) heating accounts for 15% to 27% of the total energy use in Minneapolis apartment buildings, not counting the energy used for lighting and domestic appliances (Dunsworth et al. 1988). To date, very little research has focused on retrofits aimed at reducing DHW energy use. This lack of reliable data makes it difficult for multifamily building owners to select appropriate options for DHW heater upgrades or replacements. As a result, owners tend to select controls and equipment based on lowest first cost and familiarity, which often means lower efficiency. Efficiency improvements which cost even a few hundred dollars are often not implemented due to the lack of verifiable savings data. To rectify this, the Energy Resource Center (ERC) and the Minnesota Center for Energy and Environment (MNCEE) investigated several promising strategies aimed at reducing DHW consumption in apartment buildings. This paper reports on the results of one of these studies.

Perhaps the best opportunity for efficiency upgrades to DHW heating in multifamily buildings is at the time of equipment replacement. While significant work has been done on developing and marketing high efficiency heating and DHW appliances suited to single family homes, very little has been done in a similar vein targeted to multifamily buildings. In addition, efficiency testing and rating of hot water heaters by the Gas Appliance Manufacturers Association (GAMA) does not typically include equipment appropriate for apartment buildings since it is restricted to gas tank-type heaters with inputs of 75,000 Btu/h or less (GAMA 1991). Other than using a high efficiency residential heating boiler with a storage tank, there are limited high efficiency options available for heating DHW in larger residential buildings. Furthermore, operating costs cannot be compared very easily among alternatives due to the lack of standardized ratings. Consequently, building owners have little incentive to seek out high efficiency DHW heating equipment, and in fact the lack of performance data on various options may act as a deterrent to those owners who want to install such equipment.

In order to narrow this information gap, existing conventional tank-type DHW heaters in two buildings were replaced with high efficiency condensing water heaters estimated at 90% thermal efficiency. The purpose was to measure savings from this retrofit, as well as to asses the performance of the "best available technology" for this application.

SAMPLE BUILDINGS

Since the particular replacement water heaters used in this research were only available with a relatively small capacity (i.e.; input of 100,000 Btu/h and capacity of 34 gallons), the test sites also needed to be fairly small (5 to 10 unit).[1] However, this range of building size makes up at least 42% of all 5+ multifamily buildings in Minneapolis and 13% of the total dwelling units (Quaid, et al. 1986), with a similar breakdown likely in St. Paul. As a result, this building sector was a good one to address for this retrofit.

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[1]The same manufacturer now makes a somewhat larger unit with a capacity of 50 gallons instead of 34, but the rated input is still 100,000 Btu/h.

Potential sites were selected from among buildings which had been audited by the Energy Resource Center. Besides the size criteria, sites were selected based on the type of existing DHW system (i.e.; tank type heater without a recirculation loop), the convenience of location, and the interest of the owner in participating in the study. In addition, annual DHW use at the final sites was compared to a larger sample of audited buildings to make sure that it was reasonably typical for buildings of this size. As a result of this search, two sites with average DHW use were selected for this project.

Both buildings are older (circa 1910) and have forced hot water heat with a single heating zone for the entire building. (Photographs of these buildings are found in Appendix A.) One of the test sites is a three and three-quarter story (including basement), six unit, multifamily building with twelve tenants (Table 1). This building is actually a converted fourplex, with a fifth unit added to the basement and a sixth added to the attic. The second site is an as-built apartment with three stories (including basement), nine units and twelve tenants (Table 1). These two building types each make up a large portion (34% for the conversion apartment and 52% for the as-built apartment) of the multifamily buildings which are under 10 units, so they are quite representative of buildings in this size range (Quaid, et al. 1986).

TABLE 1. Description of DHW Test Sites

	Site 1	Site 2
Year Built:	1911	1913
# Stories:	3.75	3
# Units:	6	9
# Occupants:	12	12
# Dishwasher:	0	0
# Wash Mach:	1	1
DHW Htr Type:	Tank	Tank
# of DHW Htrs:	1	1
Htr Capacity Gal:	50	75
Rated Input (Btu/h):	40,000	76,000
Measured Input (Btu/h):	34,500	74,800

Neither building has dishwashers but both have on-site laundry facilities. Each site had one existing gas-fired, tank-type hot water heater controlled by a constant temperature aquastat supplied by the original equipment manufacturer. The tank heater at site 1 was 50 gallons and had a rated input of 40,000 Btu/h, whereas the unit at site 2 had 75 gallons and a rated input of 76,000 Btu/h (Table 1). The measured inputs for these heaters were 34,400 Btu/h and 74,800 Btu/h respectively for the two sites, which are 14% and 2% lower than the rating. The GAMA energy factor for the heater at site 1 is 0.54. No energy factor for the heater at site 2 is available, since it has a rated input of over 75,000 Btu/h.

EXPERIMENTAL DESIGN

Strategies Tested

In order to assess the performance of the "best available technology" for this application, a very high efficiency, condensing water heater was selected for field testing in this project. Based on a review of equipment completed by the researchers, this unit was among the few commercially available high efficiency water heater technologies for this building sector. The DHW heater tested is a residential tank-type hot water heater with pilotless ignition, forced combustion, a capacity of 34 gallons, a rated input of 100,000 Btu per hour, and a recovery rate of 124.5 gallons per hour at 90°F temperature rise. (See Appendix B for complete specifications and product literature.) The heater has an estimated recovery efficiency of 90%. While this DHW heater is too large to be rated by GAMA, the manufacturer estimates an energy factor of about 0.86 for this equipment (Stewart, pers. comm.).

At each test site, the existing tank-type hot water heater was left in place, with the high efficiency condensing hot water heater installed in parallel with the old system, and plumbed with the capability of supplying hot water to the building independent of the existing system. At site 2, the DHW demand was expected to be large enough that a 50 gallon storage tank was installed in addition to the high efficiency heater to provide additional capacity. In this later system, incoming cold water from the city was directed to the inlet tap on the high efficiency water heater and a supply tap from the high efficiency water heater was connected to the inlet tap on the separate storage tank. (See Appendix B for schematic.) In addition, a pipe with a circulation pump was connected from a different tap on the storage tank to the inlet tap on the high efficiency heater. That way if temperatures in the separate tank drop below a preset limit, water is circulated from the separate tank to the high efficiency heater until the temperature is satisfied. Hot water was supplied to the building directly from the separate storage tank.

The parallel installation created two modes of operation for each test site: DHW supplied to the building by the existing water heater, and DHW supplied by the high efficiency water heater. During an initial trial period, the operating temperature of the hot water heaters was adjusted so that the temperature of water supplied to each building by either system was roughly the same for both test modes. For site 1, the setpoint of the conventional tank was midway between hot and warm and the measured, volume-weighted average of hot water actually supplied to the building was 129.7°F. The setpoint of the high efficiency water heater at this same site was at around 140°F, and the temperature of hot water actually supplied to the building averaged 132.5°F. For site 2 the setpoint of the standard efficiency heater was also midway between hot and cold, whereas the measured, volume-weighted average of hot water supplied to the building was 120.0°F. The high efficiency heater at site 2 had a setpoint of roughly 130°F, with an average supply temperature of 120.8°F. Throughout the nine month test period, operation of the existing tank-type DHW heater in each building was alternated with the new high efficiency tank-type heater for one week periods.

Monitoring

Operation of the DHW system in each building was monitored with a computerized data acquisition system (DAS) during each of the two test modes. (See Appendix A for a photograph of the monitoring equipment.) The DAS collected hourly average data, including heater run-time and events, hot water supply temperature, cold water inlet temperature, boiler room temperature and outside temperature. Besides data collected by the DAS, a gas submeter was installed at each building and read manually on every switch-over day. In addition, a mechanical run-time meter was installed on the circulation pump between the high efficiency hot water heater and the separate storage tank at site 2. This was read at switch-over in order to obtain an estimate of how often water from the storage tank needed to be recirculated through the DHW heater to maintain desired temperatures.

Piston-type, positive displacement water flow meters were installed on the cold water inlet lines to measure the volume of water supplied to the water heaters. These meters were equipped with impulse contact registers that open or close an electrical circuit every time two-and-a-half gallons of water flow through the meter. Each time the DAS measured two-and-a-half gallons of water entering the water heaters, the heat output (demand in Btu) was instantaneously calculated by multiplying the water volume, the average difference in the supply minus inlet water temperatures since a volume of water was last indicated, the heat capacity and the density of the water at the measured inlet temperature. This calculated heat output was summed over each one-hour period and recorded by the DAS.

Analytical Methods

Data were collected from July 1991 to March 1992. Some data were eliminated from the analysis for various reasons, including data on days when the switch-over occurred as well as at times when the DHW heaters were not working properly, when the DAS malfunctioned, or when a building-specific problem affected the result. The overall data capture rates (i.e.; number of days of usable data divided by the total number of days the system was monitored) were 76% and 66% respectively for sites 1 and 2 (Table 2). If switch-over days are ignored, data capture rates were 87% and 73% for the cases.

TABLE 2. Data Capture Rates

	Site 1		Site 2	
	# Days	%	# Days	%
Total Monitored:	226	100%	225	100%
Switch-over:	29	13%	22	10%
DHW Equip Problem:	0	0%	24	10%
***Data Quality Problem**	25	11%	0	0%
DAS Problem	0	0%	31	14%
Usable:	172	76%	148	66%

*Data collected on these days were not used in the analysis due to high standardized residuals relative to the regression model.

Previous research has shown that daily average energy input (Btu/h) and output (Btu/h) data from commercial tank heaters fit a linear model (Nevitt and Stefanson 1988). In order to use this model for analyzing data collected in the research, daily average inputs and outputs were computed for each DHW heater mode at each site in the following manner. To obtain the average daily input, hourly burner run-time data collected by the DAS were reduced to a daily average which was multiplied by the DHW heater input. For the existing tank heaters, the estimated pilot use was added to the burner input to obtain the total input.[2] (Gas meter readings were used to confirm gas use estimates calculated by the DAS.) To obtain the average daily output, hourly calculated heat output was summed and averaged. A linear regression analysis of daily DHW heat input vs. output was performed with the data for each mode in each building. This model of gas use was extremely well-defined for both modes of operation at both sites 2 (R-squared > 0.98). (See Appendix C for exact regression parameters).

Parameters from these regression models can be used to calculate the annual average input required for each heater mode based on the annual average output (demand) for each building. However, determining the annual average output for each building required normalizing the calculated daily heat outputs for inlet water temperature, which varies strongly by season (from almost 34°F to 82°F as measured at the city water treatment plant).[3] This normalization was a four step process. First, daily inlet temperatures at each site (both modes combined) were regressed on daily average supply water temperatures for Minneapolis over the same period (Appendix C). Second, these regression parameters were used to calculate a normalized annual inlet water temperature for each site corresponding to the long-term treatment plant average of 52.4°F. For the two sites, the normalized temperatures were 62.8°F and 62.5°F respectively. Third, a linear regression of daily DHW output to measured on-site inlet water temperature was performed for each site, using the data from both modes (Appendix C). Fourth, employing the parameters from this second regression and the site-specific annual average inlet water temperature estimated from the previous regression, a normalized annual average output for each building was determined.

RESULTS

Energy Use and Savings

Results of input versus output regression analysis for sites 1 and 2 are shown respectively in Figures 1 and 2. Each square on figures 1 and 2 represents a daily average input/output from times when the system was operated by the existing DHW heater. Similarly, each X represents an average from times when the system was operated by the replacement high efficiency heater. The regression lines are also displayed in the figure and indicate that the high efficiency heater requires far less input than the standard tank heater to meet the same demand (output).

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[2] *Burner and pilot input rates were computed from a regression of weekly gas use on the operating hours and total hours.*

[3] *Simple raw averages of calculated heat outputs was not used, since the periods when each control was operating were not strictly representative in terms of average inlet water temperatures; therefore, input values based on raw averages could be biased.*

FIGURE 1. Model of Gas Use

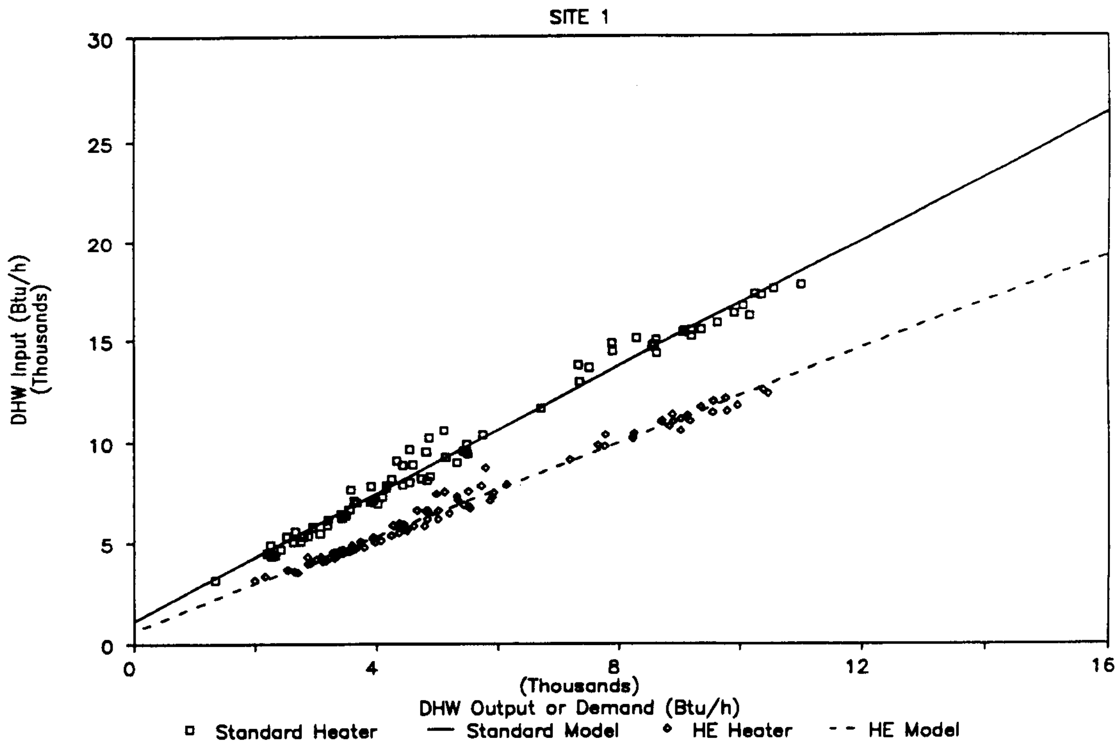
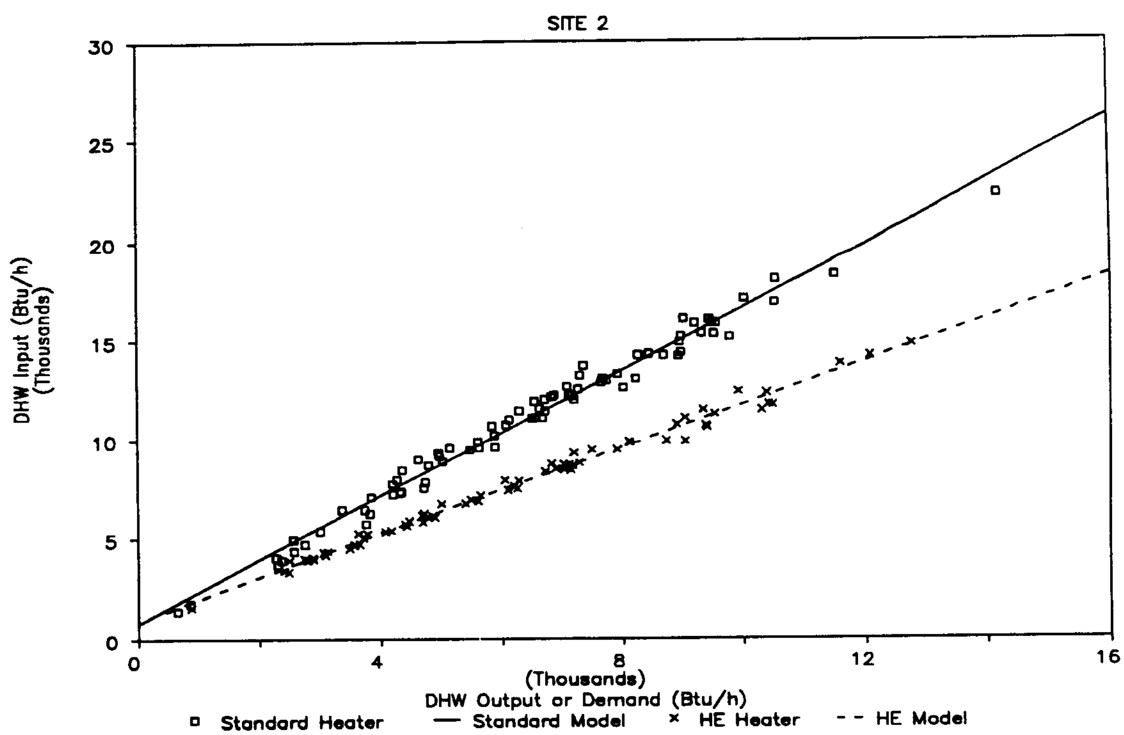


FIGURE 2. Model of Gas Use



As already discussed, a normalized annual output (Btu/h) for each building was determined and used with the regression models in Figures 1 and 2 to determine an average annual input for each mode of operation in each building (Table 3). The normalized annual output for site 1 was 5,380 Btu/h with calculated inputs of 9,650 Btu/h for operation with the standard efficiency water heater and 6,920 Btu/h for the high efficiency heater. At site 2, which had a normalized annual output of 6,220 Btu/h, corresponding calculated inputs were 10,600 Btu/h and 7,650 Btu/h respectively for the standard and high efficiency heaters.

Measured seasonal efficiencies (output over input) for the conventional tank-type water heaters monitored at sites 1 and 2 were 55.8% and 58.5% respectively (Table 3). The heater at site 1 operated roughly 28% of the time, while the heater at site 2 operated about 14% of the time. Given the higher efficiency and lower operating times of the heater at site 2, it is likely it has lower off-cycle losses than the unit at site 1. The energy factor for the tank heater at site 1 was 0.54, which is quite close to what was observed. No energy factor was available for the heater at site 2 since this rating is not required for heaters larger than 75,000 Btu/h. Other researchers have reported seasonal efficiencies ranging from 51% to 65% for similar tank-type heaters without recirculation loops (Robinson et al. 1986, 1988; Nevitt and Stefanson 1988; Nevitt 1989). This matches closely with what was found in this study.

TABLE 3. Results of High Efficiency Heater Study

	Standard DHW Htr	High Eff DHW Htr
SITE 1		
Annual Output Btu/h:	5,380	5,380
Annual Input Btu/h:	9.650	6,920
Annual Efficiency %:	55.8%	77.7%
% Savings:	n/a	28.2% ***
SITE 2		
Annual Output Btu/h:	6,220	6,220
Annual Input Btu/h:	10,600	7,650
Annual Efficiency %:	58.5%	81.4%
% Savings:	n/a	28.1% ***
MEAN		
Annual Efficiency %:	57.2%	79.6%
Savings Over Std Htr:	n/a	28.2%

*** Highly Statistically Significant ($P < 0.001$)

NOTE: Values calculated directly from figures in this table may differ from the results in the table due to rounding

By comparison, seasonal efficiencies (output over input) for the high efficiency DHW water heaters tested at sites 1 and 2 were 77.7% and 81.4% (Table 3), with corresponding run-times of about 7% and 8%. The difference between the measured efficiencies for these two identical DHW heaters may be partially explained by the fact that the heater at site 1 was operated at a higher temperature (in the range of 130°F to 140°F), compared to the heater at site 2 (in the range of 120°F to 130°F), and by the fact that the DHW load at site 2 is slightly higher. (Referring to Table 3, the output at site 2 is about 16% higher than at site 1. Site 2 has 50% more units, but the same number of tenants as site 1.) While no GAMA energy factor is available for this heater since it has an input larger than 75,000 Btu/h, the measured efficiencies (77.7% and 81.4%) are somewhat below the estimated energy factor from the equipment manufacturer, which is 0.86. However, for site 2 it was expected that the added storage tank would reduce the efficiency from that obtained using the high efficiency heater alone. Measurements conducted over a one month period were made to study the efficiency of the heater operating alone. From this limited data (26 days) the seasonal efficiency was found to be 84.4%, which in this case is very close to the manufacturer's estimate of 86%.

As might be expected from looking at Figures 1 and 2, measured savings from the high efficiency heaters were substantial. Estimated savings were 28.2% of annual DHW consumption for site 1, and 28.1% for site 2. Both of these results are highly statistically significant ($P < 0.001$). These savings correspond to annual energy reductions of 23.9 MBtu (239 CCF or therm) for site 1, and 25.8 MBtu (258 CCF) for site 2.

Cost and Payback

Annual operating costs for providing DHW with the conventional tank heaters were estimated at $420 at site 1 and $470 at site 2, based on a fuel cost of $0.50 per CCF (Table 4). Providing the same hot water with the high efficiency heaters would cost $300 and $340 per year respectively for the two sites. This yields an annual savings of $120 and $130 for the cases investigated.

The installed cost of the high efficiency heater at site 1 was $2,800 (Table 4). At site 2, installed costs were higher ($3,500) due to the additional installation of a separate storage tank. Costs for this second case could have been reduced by about $500 (to $3,000 total) if the larger high efficiency heater with the 50 gallon storage tank had been available at the time of retrofit, since the separate storage tank would have then been unnecessary. Costs in the range of $3,000 are considerably higher than the cost of installing conventional DHW heaters. For example, for these two cases the contractor estimated the cost of installing replacement heaters comparable to the existing heaters at $550 for site 1 and $950 for site 2 (Table 4).

Paybacks based on the total cost of the high efficiency heaters are 23.3 years for site 1 and 26.9 years for site 2, with an average of 25 years. For site 2, paybacks would have been reduced to 23 years if the 50 gallon high efficiency heater could have been installed. Paybacks like this are a poor inducement to an owner to replace a working hot water heater with a high efficiency unit. Even in the case where a new hot water heater is required, the added cost of the high efficiency heater is large. Based on contractor estimated prices, the cost differential for the high efficiency heaters in these cases were $2,250 and $2,550. Paybacks calculated on this marginal cost are roughly 19 to 20 years, still much larger than most owners are willing to accept without some sort of additional incentive. In addition, 20 years is at the edge of the life expectancy for a heater of this type.

TABLE 4. Costs & Paybacks For High Efficiency Heaters

	Standard DHW Htr	High Eff DHW Htr
SITE 1		
Annual DHW Cost/Yr*:	$420	$300
Heater Installed Cost:	$550	$2,800
Savings/Yr:	n/a	$120
Payback (Yrs):	n/a	23.3
Marginal HE Cost**:	n/a	$2,250
Marginal Payback (Yrs):	n/a	18.8
SITE 2		
Annual DHW Cost/Yr*:	$470	$340
HE Htr Installed Cost:	$950	$3,500
Savings/Yr:	n/a	$130
Payback (Yrs):	n/a	26.9
Marginal HE Cost**:	n/a	$2,550
Marginal Payback (Yrs):	n/a	19.6
MEAN		
Savings/Yr:	n/a	$125
Payback (Yrs):	n/a	25.1
Marginal Payback (Yrs):	n/a	19.2

* Based on fuel cost of $ 0.50 per 100,000 Btu (one therm)

** Based on cost differential between HE & Standard heater

Operation

At site 1, the high efficiency unit was installed about six months prior to the start-up of monitoring. During this period and for the duration of the tests, no difficulties were encountered with the heater. At site 2, the high efficiency unit was installed about a month prior to the test period. During the test period, this particular heater did experience several problems. Twice during the first six months of operation, the unit failed to fire when there was a call for hot water. In both cases, the heater was reset by researchers as per instructions provided by the heater manufacturer. The unit functioned without difficulty for several months after each reset. However, about six months into the project, the heater at site 2 developed an irreparable leak and had to be replaced. This new heater failed to fire on a call for hot water about two weeks after it was installed. In this case, simply resetting the unit also took care of the problem. However, about three months after this occurred, a leak developed in the replacement water heater. As a result, the second unit was removed from the site and another new heater installed. This second replacement unit has experienced no operating problems to date (about 4 months of operation). As of this writing, the manufacturer has yet to communicate the cause of the initial failures and leaks to the research team, although identical problems have been seen with similar equipment made by the same manufacturer (Bohac, et al. 1991). It should be noted that equipment failures are not uncommon when new technologies are field tested, and that manufacturers generally respond to such difficulties by making appropriate equipment upgrades, or modifying designs. In addition, in this project the manufacturer was quick to back-up their product and provide factory support. All work entailed in replacing the units was completed by the contractor under warranty.

Formal tenant surveys were not conducted at these sites since the replacement equipment was not expected to affect tenant satisfaction, however caretakers were expected to report any complaints. For this research project, tenant complaints only occurred at site 2, when the high efficiency heater failed during operation, resulting in too low DHW temperatures. The caretakers reported no other operational difficulties.

From data collected throughout the test period, it seemed possible that the separate tank installed at site 2 may have been superfluous. For example, the typical peak demand at site 2 ranges from 65 to 90 gallons per hour, whereas the recovery rate for the high efficiency water heater is about 124 gallons per hour at 90°F temperature rise. Therefore, even during the winter when inlet water temperature were lowest (around 40°F) the unit should have the capacity to cover the building's demand. In order to test this theory, the DHW system at site 2 was operated for a period of about a month with water supplied to the building directly from the high efficiency heater. This period occurred after the formal test period and monitoring had been completed. While there were no tenant complaints, the data collected during this test period indicate that the ability of the high efficiency heater to meet the demand without the extra storage capacity was somewhat marginal. Specifically, from looking at hourly profiles during this period of operation, the supply temperature tended to drift downward, sometimes reaching as low as 90°F to 100°F, during periods of sustained demand. Since this test was done during a period when inlet water temperatures were mild (generally 55°F or higher), one could infer that winter operation would aggravate this trend, possibly resulting in insufficient hot water to meet tenants' needs. However, it is likely that the 50 gallon heater now available from the same manufacturer would be adequate to meet demand without a separate storage tank.

CONCLUSIONS

High efficiency condensing tank-type hot water heaters installed in two smaller (6 and 9 unit) multifamily buildings had savings of 28% of annual DHW costs when compared to operation with a standard efficiency tank-type heater. This corresponds to annual savings of about 24 MBtu and 26 MBtu repectively for the two cases investigated. Since both of these buildings were smaller, with relatively modest DHW loads, comparable dollar savings were only about $120 to $130 annually.

The seasonal efficiency of the high efficiency heater operated alone was measured at 78%, which is somewhat lower than the manufacturer's estimate of 86%, perhaps due to the fact that this heater had operating temperatures which were fairly high (in the range of 130°F to 140°F). Seasonal efficiencies for the second high efficiency heater were 81% when operated with the attached storage tank and 84% when operated alone, measurements which are considerably closer to the manufacturer's estimate, possibly as a result of lower operating temperatures and a slightly higher load. Comparative seasonal efficiencies for the standard tank-type heaters monitored in this study were 56% and 59%, which is comparable to efficiencies measured by others for similar DHW heaters.

Installed costs for the high efficiency hot water heater were quite high: $2,800 at one site and $3,500 at a second where a separate storage tank also had to be installed to meet anticipated demand. As a result, even with savings of 28%, paybacks based on total costs are 23 to 27 years. Paybacks like this are no inducement to an owner to replace a working hot water heater with a high efficiency unit. Even in the case where a new hot water heater is required, the added cost of the high efficiency heater is substantial, and paybacks are only reduced to about 19 or 20 years, still much longer than most owners are willing to accept without some sort of additional incentive. However paybacks will improve as larger units, applicable to buildings with a higher annual DHW demand, become available.

While one heater operated flawlessly throughout the test period, the other had problems with periodic failure of the igniter and unrepairable leaks. Given that similar equipment available from the same manufacturer has had identical difficulties in another study, this technology is not yet problem-free. This is a deterrent for equipment intended for use in multifamily buildings since our experience indicates that these type of owners are very sensitive to tenant complaints and are desirous of maintenance free mechanical equipment. Based on our review of available equipment for this application, development of more and better options for replacement of DHW equipment in multifamily buildings is certainly warranted.

ACKNOWLEDGMENTS

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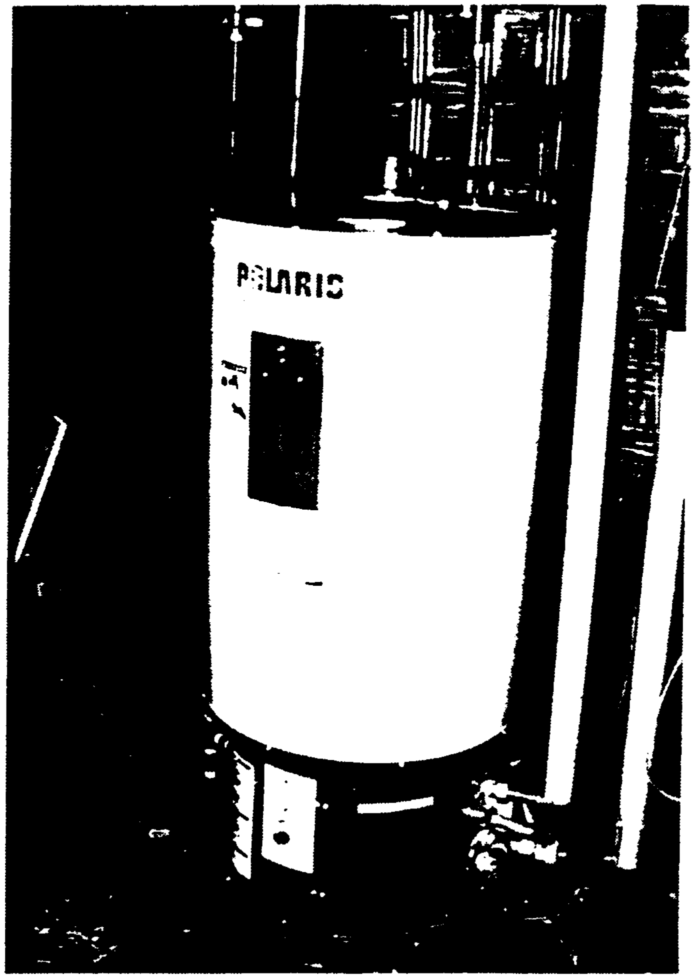
APPENDIX A

Building Site 1

Building Site 2

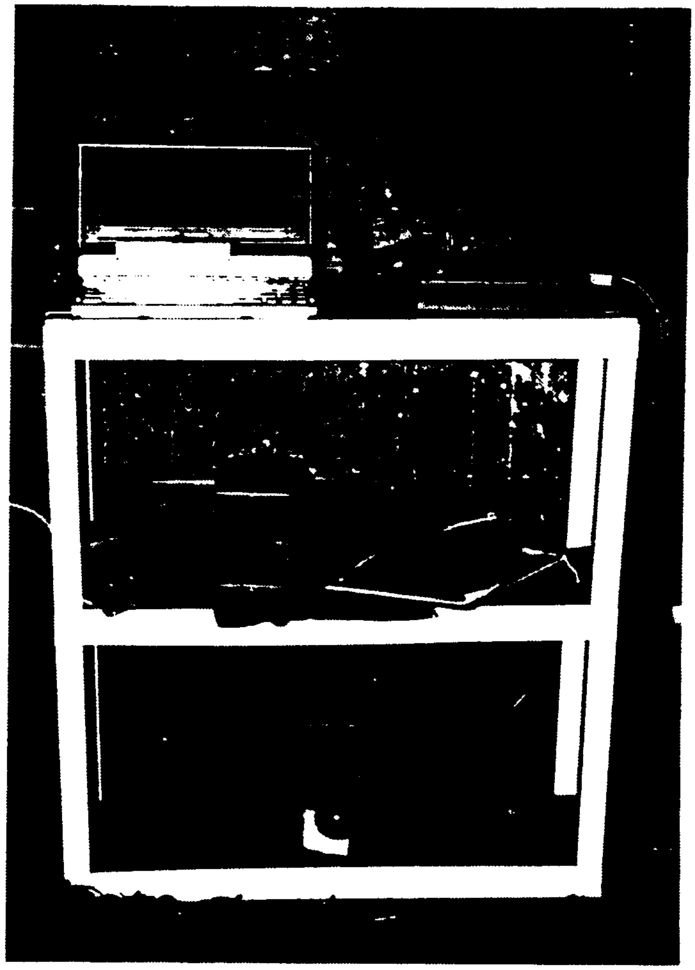
APPENDIX A (continued)



High Efficiency Heater at Site 1

High Efficiency Heater, Existing Heater, Storage Tank (L to R) at Site 2

APPENDIX A (continued)

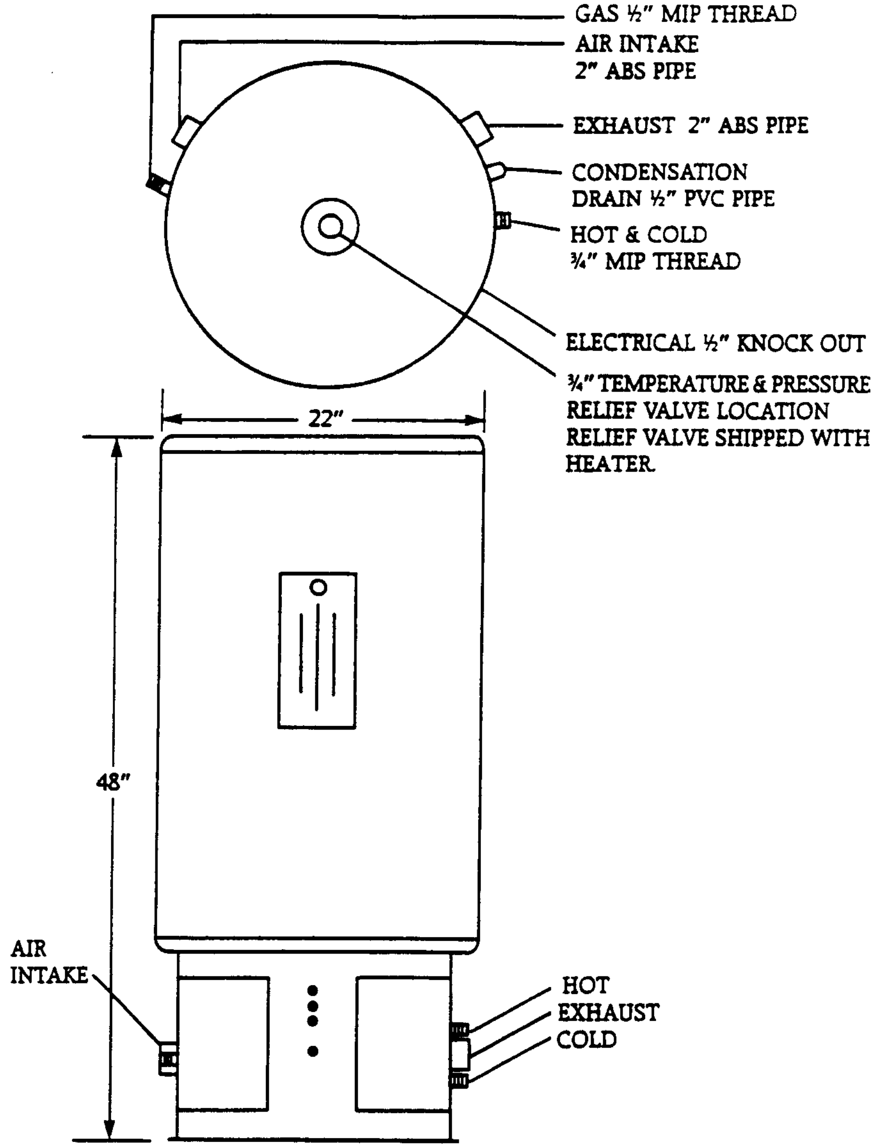


Data Acquisition System

Specifications for the High Efficiency Water Heater

POLARIS SPECIFICATIONS

DVPB	35
Part No.	0300272
Capacity (gal)	34
Nat. Gas Input (Btu/hr)	100,000
*Nat. Gas Output (Btu/hr)	94,000
Recovery Efficiency	94%
*Recovery @ 90°F Rise (gal/hr)	124.5
R Factor	16.6
Shipping Weight	136 lb
10-year Limited Tank Warranty	



*Input, output and recovery may vary depending upon air inlet and vent outlet installations. Length and number of bends in inlet and outlet pipes may reduce input, output and recovery efficiency.

All technical specifications subject to change without notice.

Mor-Flo Industries is recognized as the leader in the development of new, energy efficient water heating products.

As a result of this on-going commitment, new and innovative water heating technologies have been established and incorporated into a series of proven products that include energy saving residential and commercial water heaters; the first water heater with a submerged combustion chamber; solar water heating systems; heat pump water heaters; and now Polaris — the first in a series of space/water heating Comfort Systems.

Good reasons why Mor-Flo Industries, the only independent, publicly-held water heater manufacturer in the United States, is one of the fastest growing companies in the industry.

MOR-FLO®/AMERICAN®
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MOR-FLO INDUSTRIES, INC.
18450 South Miles Road
Cleveland, Ohio 44128-4296
(216) 663-7300

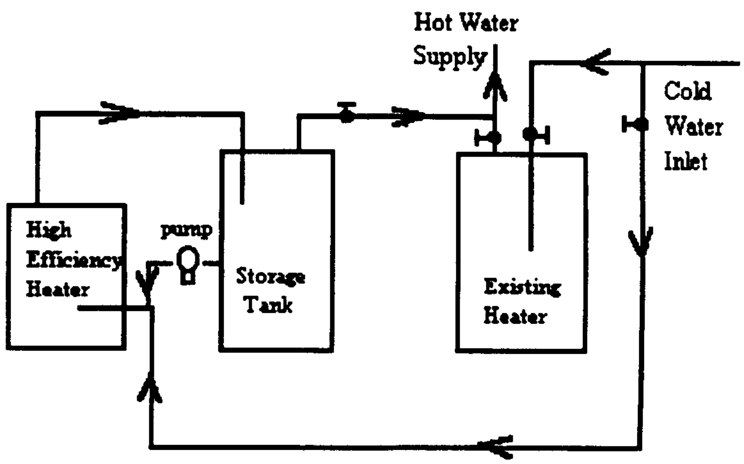
Available from:

AMERICAN APPLIANCE MFG. CORP.
2341 Michigan Avenue
Santa Monica, CA 90404-3996
(213) 829-1755/(213) 870-8541

PB 986 CG

APPENDIX B

Piping Schematic for Site 2 (with separate storage tank)



APPENDIX C

Regresssion Results For High Efficiency Water Heater Study

SITE INLET WATER TEMPERATURE (oF) VS TREATMENT PLANT SUPPLY TEMPERATURE (oF)

	SITE 1	SITE 2
Constant	22.276	28.295
Std Err of Y Est	3.901	2.784
R Squared	0.907	0.932
No. of Observations	191	185
Degrees of Freedom	189	183
X Coefficient	0.773	0.653
Std Err of Coef.	0.018	0.013

WATER HEATER OUTPUT (Btu/h) VS SITE INLET WATER TEMPERATURE (oF)

	SITE 1	SITE 2
STANDARD HEATER:		
Constant	14487.313	16445.746
Std Err of Y Est	1598.078	1931.997
R Squared	0.636	0.439
No. of Observations	79	80
Degrees of Freedom	77	78
X Coefficients	-148.139	-167.904
Std Err of Coef.	12.766	21.489
T-statistic	-11.604	-7.813
HIGH EFFICIENCY HEATER:		
Constant	13876.282	18052.410
Std Err of Y Est	1460.228	1479.198
R Squared	0.614	0.710
No. of Observations	93	68
Degrees of Freedom	91	66
X Coefficients	-140.526	-193.483
Std Err of Coef.	11.692	15.214
T-statistic	-12.019	-12.718

WATER HEATER INPUT (Btu/h) VS HEATER OUTPUT (Btu/h)

	SITE 1	SITE 2
STANDARD HEATER:		
Constant	1146.268	764.634
Std Err of Y Est	525.768	528.592
R Squared	0.984	0.984
No. of Observations	79	80
Degrees of Freedom	77	78
X Coefficients	1.580	1.587
Std Err of Coef.	0.023	0.023
T-statistic	69.888	68.393
HIGH EFFICIENCY HEATER:		
Constant	644.553	905.774
Std Err of Y Est	316.288	283.000
R Squared	0.987	0.991
No. of Observations	93	68
Degrees of Freedom	91	66
X Coefficients	1.167	1.084
Std Err of Coef.	0.014	0.013
T-statistic	82.697	85.485