EVALUATING OPTIONS FOR THE CONVERSION OF TWO PIPE STEAM HEATING SYSTEMS TO HOT WATER HEAT: A BIDDING AND SPECIFICATION GUIDE

Mary Sue Lobenstein, George Peterson
Minneapolis Energy Office

Converting older low-rise buildings from steam to hot water heat has been shown in previous research to produce savings of 13 to 39% and result in a more even and easily controlled heating system. Conversion to hot water is most practical for Two Pipe Steam (TPS) heating systems which require minimal changes to existing distribution pipes and radiation.

Based on investigations in three multifamily buildings, options for reducing costs and optimizing performance of TPS conversion were considered. A variety of boiler retrofit options, zoning techniques and control strategies were studied. Boiler options included: converting the steam boiler to hot water, replacing the boiler, installing a steam to hot water convertor and adding a front-end boiler. Zoning options included zoning at branches, radiators, risers or apartments. Control options were outdoor resets or thermostats.

This report discusses the mechanical performance of each option as well as the costs. The advantages and disadvantages of various types of products are described. In addition, guidelines for estimating conversion costs and choosing the best option package are suggested, for use by auditors in the field. When compared with contractor's bids on the three investigated buildings, and used to specify a steam to hot water conversion for a fourth building, these estimates were close to contractors' actual bids for converting the buildings.

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INTRODUCTION

Steam to hot water (STHW) conversion is the practice of replacing the steam heating system in an older building with a hot water heating system. An earlier study completed by the Minneapolis Energy Office (Lobenstein, Hewett, Dunsworth, 1986) looked at ten converted buildings to determine the practices, savings and other benefits of the retrofit. With measured savings in the range of 13 to 39% of total annual gas use, conversion is one option worth considering. Other benefits such as increased comfort, reduced maintenance and improved property value also make conversion an attractive. STHW conversion is most practical for two pipe steam (TPS) systems, which require minimal changes to existing distribution pipes and radiation, and have paybacks in the 4 to 9 year range (Ibid). By contrast, single pipe steam (SPS) systems require a considerable amount of new piping and new radiation, resulting in paybacks of 12 to 30 years.

The previous study only looked at buildings in which conversion work had already been completed. As a result, while STHW conversion holds promise for improving heating system performance, implementation is hindered by unanswered questions regarding equipment options and conversion strategies. These choices affect savings, controllability and comfort of the building, as well as the cost of conversion. As a result, options for optimizing TPS conversions were investigated in detail for three multifamily buildings, and specified for four buildings. Using these buildings as examples, this report discusses the mechanical performance of each option, advantages and disadvantages of specific products, and guidelines for estimating conversion costs and choosing the best option package.

METHODOLOGY

Three TPS multifamily buildings owned by the same individual were examined to determine feasible STHW conversion strategies. The three cases represent a compromise between our desire to look at a variety of buildings, and our staff constraints.

Two contractors active in STHW conversion, and a third contractor of the owner's choice, were given detailed conversion options to consider for each building. Each contractor examined the buildings at length and was asked to deliver bids detailing specific equipment with item-by-item installation costs. Initially, all three contractors only provided general bids without item-by-item costs. Due to lack of interest, the third contractor dropped out of the process at this point. More detailed information and price breakdowns were assembled from various phone conversations with the remaining two contractors and equip-ment distributors. Independent of contractors' bids, several products used in steam to hot water conversion were investigated to compare features, performance and overall quality.

Generalized STHW conversion guidelines were developed based on information gathered in this investigation. These guidelines were used to specify and estimate the cost of STHW conversion systems in the three researched buildings plus one additional building. Estimates were compared to contractors' actual bids to determine reliability of the guidelines.

BOILER OPTIONS

When a STHW conversion takes place, several options are available for the boiler: the boiler can be converted to hot water and reused, the boiler can remain steam with a steam to hot water heat exchanger installed between the boiler and the distribution system, the boiler can be replaced, or a front-end boiler can be added.

Boiler Conversion

Conversion of the existing boiler is the least expensive option, but it must be in good condition and able to withstand the maximum water pressure (usually 30 psi) of the proposed system. Converting a boiler requires removal of the steam header, check valves, hartford loop, low water cutout, and condensate tank with pump and piping if present. The sight glass, water column, pressure relief valve, pressure gauge and pressuretrol(s) are removed and replaced with a hot water compatible pressure gauge, thermometer, pressure relief valve and aquastat. An expansion tank must be added to the system. These changes generally cost $1100 for most boilers (300,000 to 1,000,000 Btu/hour input). In addition, there are several options that can add from $200 to $3000 to conversion costs. These include installing a new low water cutout, a vent damper or a new power burner, tuning up the existing burner, and repairing or replacing existing steel fire tubes.

A low water cutout, although not required on hot water boilers in Minneapolis, provides an excellent safety and only adds $200 to the job costs. (Note: The existing low water cutout cannot be reused on the new hot water system.)

Boiler tune-ups have been shown to give good savings on gas conversion burners (Peterson, 1984), with typical costs of $300 for an atmospheric burner. If the boiler is gas design, a general cleaning can also be recommended for a cost of roughly $150, but an actual efficiency improvement is difficult to achieve in most cases.

A vent damper can also be added. Research conducted in Minneapolis (Hewett, Dunsworth, Emslander, Koehler, 1988) using electric dampers, showed average savings of 8.5% on average for boilers with barometric draft divertors. Savings for boilers with fixed draft divertors, like those typically found on gas design boilers, were somewhat less (6.5% on average when a damper was also installed on the water heater). Costs range from $100 to $900 depending on the diameter of the vent and the type of damper installed.

While installation of a replacement burner may be a good option for a boiler with a low steady state efficiency, costs ranged from $2,000 to $3,000. Since energy savings for multifamily buildings have not as yet been documented a tune-up should be recommended first.

The repair or replacement of some or all tubes in a steel fire tube boiler may be necessary before it can be converted. Tubes that leaked under low steam pressure (1 psig or less), will need repair if the boiler is to withstand the higher pressure (30 psig) of a hot water system. In the case of a boiler that has never leaked, it may be difficult to determine whether the tubes will hold up. Costs are roughly $100 for repair of up to four tubes. Replacement is $150 per tube, or up to $3,000 for replacement of all tubes. Thus, if a large number of tubes need replacement, a new boiler should be considered.

Two products typically installed as part of a boiler conversion were investigated in more detail. These were expansion tanks and low water cutouts. There are two basic kinds of expansion tanks: air cushion and diaphragm. In either type, trapped air compresses as system water heats and expands. In the cushion type, air directly contacts water within the system. In the diaphragm tank, air and water are physically separated, which prevents re-absorption of air into the distribution water. As a result, a diaphragm tank is more effective at keeping air out of the system, a particularly important feature with cast iron radiators which have a tendency to trap air at the top of columns. For low water cutouts, there are two basic choices: a float type mechanical cutout or a probe type electronic cutout. Checking with a few manufacturers, it appears that the electronic type is somewhat cheaper and more dependable.

<u>Steam to Hot Water Convertor</u>

STHW conversion can also be achieved by leaving the existing steam boiler unmodified, converting the distribution system to hot water and installing a STHW heat convertor.

Since the cost of installing a steam convertor ($3000) is roughly twice the cost of converting a cast iron boiler, it is not recommended in these cases. However, it appears to be a competitive option for steel fire tube boilers since the cost of repairing suspect fire tubes can be greater than the cost of the convertor. For the only steel fire tube boiler investigated in this study (Building A), the cost of retubing and converting would have been $4,000, compared with $3,100 for the convertor. A convertor also provides a cheaper way to achieve outdoor reset in multizone buildings. A converted steel fire tube boiler would require a three-way mixing valve to allow reset. If a convertor is installed, a simple on/off reset can be used. Installing a convertor also compares well with the option of replacement boilers which cost $6,000 to $10,000 (600,000 to 1,000,000 Btu/hour input).

Steam convertors are simple and reliable, but energy savings in this application are unknown. If the existing boiler is marginal, the $3,000 may be better spent on new boilers.

Boiler Replacement

In the case of an unsalvageable boiler, replacement is the only option. Replacement boilers may also be dictated by owner preference or other considerations such as increased seasonal efficiency or improved property value. Since all of the boilers were replaced in the previous STHW study, it is unknown how much of the observed savings (24% on average) are due to improved distribution or control, and how much is due to increased boiler efficiency. Quite likely, it is related to what type of boiler is being replaced. Observed seasonal efficiencies of existing boilers range from a low of 50% for a large brickset steel fire tube boiler (Modera, Diamond, Brunsell, 1986) to a high of 79% for a cast iron packaged boiler (Robinson, Nelson, Nevitt, 1987).

The proper choice for a new boiler or boiler system is a complex subject beyond the scope of this study, but in general there are several options. A conventional new cast iron or steel fire tube boiler can be installed. In many cases, installation of two or more efficient conventional boilers, fired modularly to meet building load, is a better alternative than the installation of one large boiler (Kelly, Didion, 1975). When the design criteria can be met a front-end boiler could also be considered.

Installation of a Front-End Boiler

The front-end boiler concept combines a high efficient boiler with a conventional boiler (usually the existing boiler). Such a system can be designed to just supplement the heating, or to provide domestic hot water as well. The later strategy, which takes year round advantage of the system's added efficiency, is more cost effective and should be designed to provide the entire domestic hot water load and at least 50% of the design heating load (Robinson, Nelson, Nevitt, 1987). If these sizing guidelines can be met, a front-end boiler can be considered with the caveat that such systems are complex and require a well-engineered design, installation by a knowledgeable contractor, and ongoing monitoring to be successful.

PIPING AND RADIATOR OPTIONS

Although a TPS distribution system is compatible with hot water, several piping changes are required. Unnecessary equip-ment, such as steam traps, air vents and extra return lines must be removed. In addition, condensate return lines located in the basement cement floor are routinely replaced because they tend to corrode and often leak after conversion.

Two options are available for the piping layout of the new system: reverse return or direct return. A reverse return system (Figure 1) is one "in which the heat distributing units (in this case radiators) are connected to the return main in the reverse order from that in which they are connected to the supply main" (Hydronics Institute, 1973, p 3). As a result, the length of the circuit and hence resistance through each radiator is roughly equal, keeping the system balanced. Alternatively, a direct return system (Figure 2) is one "in which water from the heat distributing units is returned to the boiler by the shortest feasible path" (Ibid). This layout is less expensive to plumb, but results in balancing problems since the length of the circuit and resistance through radiators close to the boiler is much less than through radiators farther from the boiler.

TPS buildings typically have radiators compatible with hot water (i.e. sections are connected at the top as well as the bottom). If not, STHW conversion may not be practical since new baseboard radiation must be installed at considerable cost. When radiators are compatible, several changes are still required. First, a hole is drilled at the top of each radiator and an air bleeder valve inserted. Second, radiator traps are removed or drilled out. (It is also possible to insert an orifice at this location. Different sized orifices inserted in radiators throughout the building could be useful in balancing the heat, particularly in a system plumbed as direct return.) Finally, the inlet valve is repacked or replaced to prevent leaks.

Whether or not the valve is repackable can account for a substantial price difference in the total cost of conversion. For the buildings investigated, costs for radiator conversion were $65 per radiator if valves were repackable, and $100 if not. A repackable valve has a nut at the top, just under the hand valve, that allows access to the valve stem seal. Conversely, a nonpackable valve has a one-piece body.

ZONING OPTIONS

Since most TPS buildings in Minneapolis are single zone, the simplest and least expensive zoning strategy is to leave the building single zone. However, dividing the building into zones would give independent control over various building areas which may have different heating requirements. This can prevent overheating and save money. The extent of overheating in a building converted as single zone hot water compared to the same building converted as multizone is currently unknown. As a result, the exact benefit of spending the extra money to zone a building is also unknown.

Four zoning techniques were investigated for the three buildings: zoning at each individual apartment, zoning at various risers, zoning at branches and zoning at each individual radiator

Apartment Zoning

The ideal zoning system has each apartment its own zone. For the buildings researched, this option was inordinately expensive, adding $14,000 to the cost of conversion. This zoning method also requires extensive wiring which is difficult to disguise. Therefore, it's not recommended.

Riser Zoning

A typical TPS building in Minneapolis has two to four supply mains in the basement from which risers feed steam to individual radiators or to a column of radiators. Zoning at these risers would yield 10 to 12 zones for most 20 unit apartment buildings. However, each zone would serve one or two radiators per floor, which does not match the heating requirements of a typical building well. The high cost of this zoning method (an additional $7,000 for the three investigated cases), also makes it an impractical option.

Branch Zoning

Dividing a building into circuits (typically two to four) based on an existing split in the main supply line is referred to as branch zoning. This method is most useful when the heating requirements of the building line up with the zones. For example, because of the way most multifamily buildings in Minneapolis are oriented, the distribution lines most often split into a North and a South branch, which is a logical division. Branch zoning is fairly economical. For one of the research buildings, it would have added $2,000 or $2,400 to the total cost of STHW conversion for two or four zones respectively. Two methods of branch zoning were investigated: zoning with pumps and zoning with valves.

For pump zoning each branch has its own circulating pump, typically controlled by a thermostat located within the living space served by the circuit. A backflow valve installed on each branch prevents water from flowing backward through the circuit when the pump is off. A possible disadvantage to pump zoning is that when all the pumps are not operating, too large a temperature rise could occur across the boiler, causing wide temperature variance.

Branch zoning with individual zone valves and a single pump is an alternative. Each valve is installed on its own circuit, and controlled by a thermostat located within the area served by that circuit. End switches can be specified for each valve and wired to turn off the pump if no zone is calling for heat. Five manufacturers of zone valves were researched for price and features. The price of the same size valve was found to vary considerably among manufacturers because particular features also vary substantially (e.g. two valves may withstand different pressures). Of the valves researched, smaller ones (2" and under) had linkages included in the motors, but an end switch had to be specified as an add-on. Larger valves had end switches built into the valve body, but had separate linkages. In addition, the largest valves (5" and larger) were only available flanged, requiring the additional specification of flanges to complete installation. The exact size valve required for a certain application depends on the thermal load of the zone.

Thermostatic Inlet Valves

Thermostatic Inlet Valves (TIVs) are self-contained temperature operated valves which are installed in place of the inlet valve on each radiator. Each radiator in effect becomes its own zone. Hot water is continuously pumped through the distribution system and the TIVs open and close to allow or prevent water flow into each radiator. The temperature sensor is either self-contained in the unit or remotely located.

TIVs give individual apartments more control over the heating, an advantage over branch zoning, but they respond slowly to temperature changes. TIVs are also more expensive than branch zoning. For a typical 20-unit building, TIVs add about $5,000 to the total cost of conversion. When the existing radiator valves need replacement, TIVs may be an option to consider. It costs about $30 more per radiator to install a TIV as opposed to a regular inlet valve.

TIVs can also be installed on just some of the radiators in a building. In this case, the pump and boiler would respond to a separate thermostat. TIVs can be put on the largest radiator(s) per apartment or in critical apartments that tend to overheat. This later strategy may be useful in combination with branch zoning. While selective installation of TIVs is less expensive than installation on all radiators, it does not give true zone control since there may not be heat available when a particular radiator needs it.

The TIVs of five manufacturers were compared; all had similar features with a few exceptions. One feature found on all brands is an internal limit (adjustable only by taking the unit apart) which restricts the maximum temperature. One brand also has a mechanical stop at 68 degrees Fahrenheit. This stop prevents accidental movement of the valve beyond 68, but can be overridden by a tenant if needed. The same manufacturer also offers a tamper-resistant model which prevents removal or theft. Three manufacturers offer a guarded TIV which only adjusts with a special tool. Four use the same valve in TPS or hot water systems, useful for the owner who wishes to convert in stages. The same suppliers have a tool for servicing the valve while the system is in operation. Although quite expensive ($300), the tool could be worthwhile for larger buildings or for owners with several buildings. Manufacturers warranties varied from one year to limited lifetime and prices ranged from $25 to $55 per valve.

CONTROL STRATEGIES

Control strategies vary for single zone and multizone buildings. In a single zone building the simplest control is a thermostat which operates the boiler on a call for heat. The pump can respond to the heat call, or run continuously. An existing thermostat can be reused, but replacement with a remote-sensing thermostat is preferred. The remote sensor allows control based on living space temperature, but the thermostat itself is inaccessible to tenants. One or more sensors can be installed. Experience in single zone steam and hot water buildings in Minneapolis and St. Paul indicates that two sensors, either one capable of operating the boiler when the temperature drops below setpoint, provide adequate control at a reasonable price. In very small (5 to 8 unit) multifamily buildings one sensor may suffice. In either case, sensor location is an important consideration.

In some cases, TIVs may be specified on only some radiators in a building. For control purposes, such a building should be treated as single zone and a thermostat installed. TIVs should not be installed in the same location as the thermostat or thermostat sensor.

The most efficient control for multizone buildings is an outdoor reset in combination with an outdoor cutout (Hewett, Peterson, 1984). Details of the control scheme depend on zoning. If TIVs are installed on all radiators, the reset and cutout can operate a cast iron boiler directly or, for a steel fire tube boiler, can operate a three-way mixing valve. The pump can run continuously except when disabled by the cutout. If the building is split into branch zones using valves, a reset and cutout should still operate the boiler. Each zone valve should also be controlled by a separate thermostat; in this case one remote sensor per thermostat should be sufficient. The pump in this scenario can run continuously, or better yet can be shut off when no zone is calling for heat so that it is not pumping against closed valves. This is accomplished by specifying zone valves with end switches that are individually wired back to the pump. The pump can also be turned off by the outdoor cutout.

SPECIFICATION AND COST ESTIMATES

As a result of investigations, the generalized steam to hot water conversion specification and cost guidelines found in Appendix A were developed. Based on these guidelines, estimates were written for the three researched buildings and one other building. Table I contains general information about the four buildings and a summary of specifications is found in Table II.

Comparison of Actual and Estimated Bids

Contractors' bids for conversion work in the buildings were compared with estimates to determine reliability of the guidelines (Table III). In general, estimates tended to run 9-10% below actual contractor bids for the same work. Eight of the seventeen estimates were within 10% of the actual bids and fifteen were within 20%.

The specification and price guidelines were primarily developed based on input from Contractors #1 and #2 using Buildings A, B and C as examples. As a result, using their bids does not provide completely independent comparisons even though the bids were provided prior to soliciting their input on the guidelines. The number of actual test cases for the bidding procedures is hence actually smaller than it appears: a bid from contractor #3 for Buildings B and C and a bid from Contractors #1, #2 and #4 for Building D. These five bids averaged about 16% higher than our estimates.

Comparing among the four buildings, costs seem fairly consistent. For single zone installations, estimates are roughly $0.60/square foot, compared with contractor bids averaging $0.67. Similarly, estimates for multizone jobs were $.70 to $.80 per square foot compared with contractor bids averaging $0.78 per square foot. Prices obtained in the previous STHW study for TPS multifamily buildings averaged $0.98 per square foot (roughly $1.15 in 1988 dollars). This is somewhat higher because all conversions in the earlier study included replacement boilers.

Savings and Payback Estimates

Savings and payback estimates were computed for all four buildings for the single zone option. Estimates were based on current total energy consumption (normalized using degree days) and assumed a savings of 15% to 20%. (An average of 24% savings was observed in the previous study, but since none of the boilers were being replaced, savings were expected to be somewhat less.) Results are shown in Table IV. Average estimated paybacks were 7 to 9.4 years.

The owner of the three heavily investigated buildings (A, B and C) decided not to convert because the payback was too long. His criteria were as follows: he would definitely have completed the work if paybacks were under four years, and probably would have gone ahead if under five; a payback of over five was questionable and over six unlikely. In each of these cases, conversion costs were considerably higher than expected. In building #A, the poor condition of the boiler added approximately $2,050 to the cost of conversion. If the boiler could have been reused, a single zone conversion would have cost $9,450 with a payback of 6 to 8 years. For buildings #B and #C, the cost of replacement inlet valves was roughly $2300. If the radiators had been repackable, single zone conversion would have been $9,140 and $8,800 respectively, with corresponding paybacks of 5 to 7 years for Building B and 6 to 8 years for Building C. While closer to this owner's payback criteria, the conversions would still have been unlikely to be completed.

The owner of Building D did complete the retrofit. The payback for this building (7 to 9 years) was no better than the other three, but in this case the owner decided the other benefits of STHW conversion offset the long payback.

CONCLUSIONS

As a result of thorough investigations in several buildings, guidelines were established for specifying options and estimating the costs of STHW conversions in TPS buildings. This has resulted in a better understanding of factors to consider when looking at this retrofit. In addition, price guidelines that were developed seem fairly accurate for use by auditors in the field, coming within 20% of actual contractors' bids. However, since these guidelines have only been tested on a small sample of buildings, additional specifications in other buildings are needed to provide further feedback.

Costs can be reduced from those documented earlier by controlling specifications, but in some cases savings may also be reduced. Paybacks appear to remain in the 5 to 10 year range, longer than many private owners will accept without some kind of incentive.

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Figure 1. Reverse return

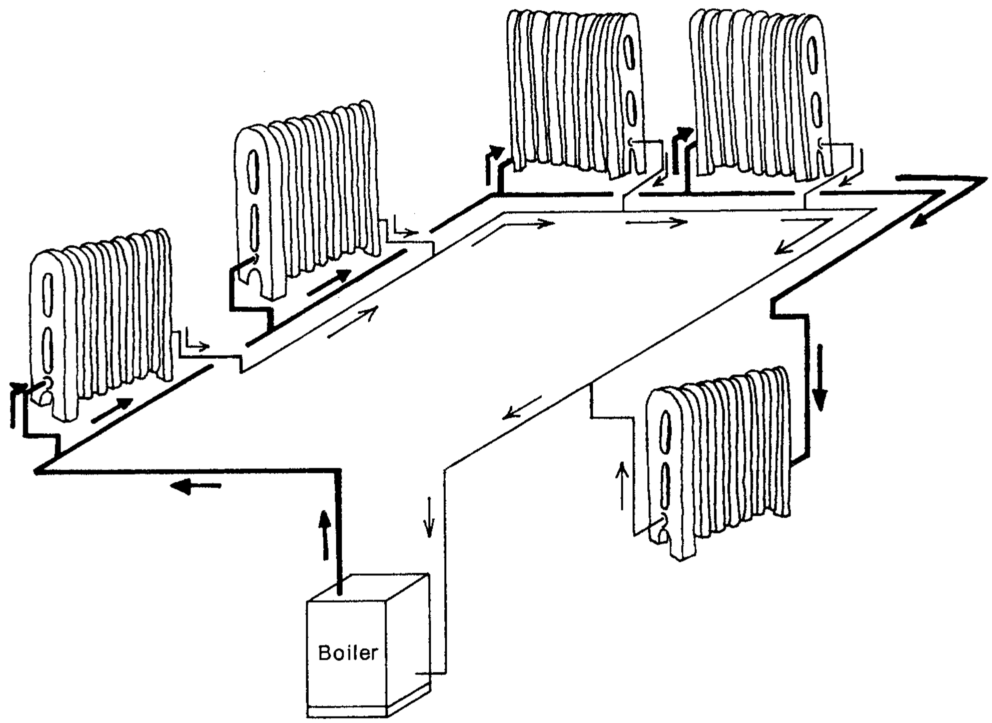


Figure 2. Direct Return

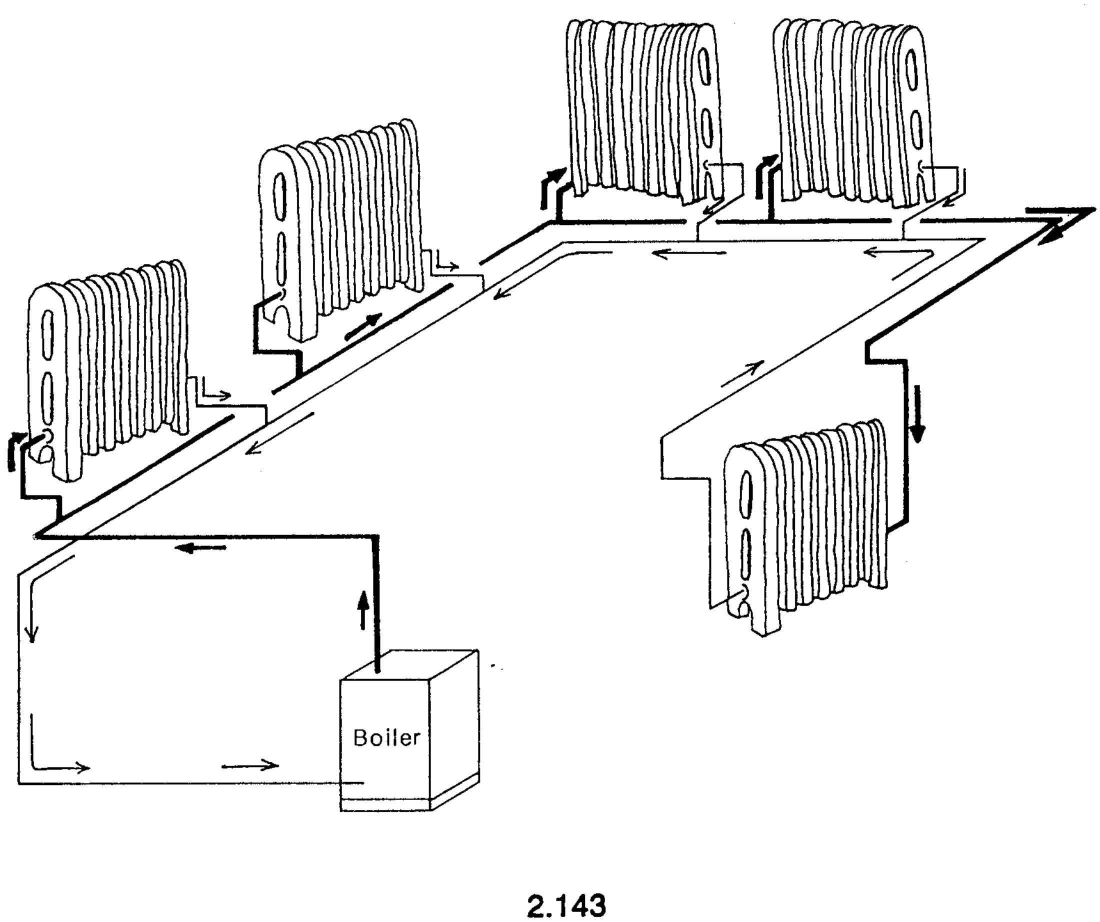


Table I. Building data

Item		Bldg. A	Bldg. B	Bldg. C	Bldg. D
General Building	Year Built	1930	1924	1928	c. 1925
	Exterior	Brick	Brick	Brick	Brick/Stucco
	Attic Insul.	R44	R44	R44	c. R40
	# Stories	4	4	4	3
	Area Sq.Ft.	19,744	19,728	18,290	7,125
# Units	Studio	1			
	1 BR	20	21	20	
	2 BR				4
Boiler Descrip.	Type	Steel Fr Tube Conversion	Cast Iron Gas Design	Cast Iron Conversion	Cast Iron Gas Design
	Year Installed	1930	c. 1965	1928	c. 1980
	Input MBtu/hr	918	975	1,000	360
	Draft Diverter	Barometric	Fixed	Barometric	Fixed
	Steady State Eff	80%	76%	81%	NA
Radiators	Total #	82	78	77	23
	ST Output MBtu/hr[1]	706	575	485	173
	HW Output MBtu/hr[2]	522	425	358	128
	Valves	Packable	Packless	Packless	Packable
Energy Use	Total MBtu/yr[3]	1,400,000	1,629,000	1,327,000	644,000
	Total $/yr[4]	$7,700	$8,960	$7,299	$3,542
Index	Total Mbtu/Sq.Ft.	70.9	82.6	72.6	89.3

[1]Based on steam at 210° F
[2]Based on hot water at 180° F
[3]Normalized using degree days
[4]Cost of gas =$.55 per CCF
One CCF = 100 Mbtu

Table II. Summary of specifications

BUILDING	A		B		C		D
Conversion Option	1 zone	4 zone	1 zone	TIVs	1 zone	TIVs	1 zone
Convert Boiler			$1,100	$1,100	$1,100	$1,100	$1,100
Install ST-HW Converter	$3,100	$3,100					
Install Vent Damper	$300	$300			$300	$300	
Install Low Water Cutout			$200	$200	$200	$200	$200
Replumb Bldg as Needed	$200	$200	$200	$200	$200	$200	$200
Replumb Wet Returns	$1,000	$1,000					
Install Pump	$1,100	$1,100	$1,100	$1,100	$1,100	$1,100	$1,100
Install Zone Valves		$2,400					
Install Controls	$500	$2,200	$500	$400	$500	$400	$435
Convert Radiators	$5,300	$5,300	$7,800	$10,140	$7,700	$10,000	$1,495
Repair Broken Valves							$120
Add-On for Built In Rad.*			$540	$540			
TOTAL	$11,500	$15,600	$11,440	$13,680	$11,100	$13,300	$4,650

* see text for explanation

Table III. Comparison of estimated and actual conversion costs

BUILDING		A 1 zone	A 4 zone	B 1 zone	B TIVs	C 1 zone	C TIVs	D 1 zone
Estimated cost from spec:*		$11,500	$15,600	$11,440	$13,680	$11,100	$13,300	$4,650
Contractor #1	Bid	$14,600	$18,350	$12,600	$15,200	$12,100	$14,700	$4,825
	Diff from est	$3,100	$2,750	$1,160	$1,520	$1,000	$1,400	$175
	% Difference	27.0	17.6	10.1	11.1	9.0	10.5	3.8
Contractor #2	Bid	$10,500	$15,750	$11,300	$13,300	$10,900	$12,850	$6,200
	Diff from est	($1,000)	$150	($140)	($380)	($200)	($450)	$1,550
	% Difference	(8.7)	1.0	(1.2)	(2.8)	(1.8)	(3.4)	33.3
Contractor #3	Bid			$12,800		$12,600		
	Diff from est			$1,360		$1,500		
	% Diff			11.9		13.5		
Contractor #4	Bid							$5,450
	Diff from est							$800
	% Diff							17.2
	Ave % Diff for B	9%	9%	7%	4%	7%	4%	18%

Average % Diff Overall: 9%
Median % Diff Overall: 10.6%

NOTE: Positive number indicates actual bid higher than estimate.
Number in parentheses indicates actual bid lower than estimate.

* Estimated costs were based on individual cost breakdowns for specific retrofit options with input from contractors #1 and #2 using buildings A, B, and C as examples. Overall bids for these cases are shaded on the table to distinguish them from other contractor bids.

Table IV. Estimated costs and paybacks

	Building A High[1]	Building A Low[2]	Building B High	Building B Low	Building C High	Building C Low	Building D High	Building D Low
Conversion Cost[3]	$11,500		$11,400		$11,100		$4,650	
Estimated First Year Savings	$1,540	$1,155	$1.792	$1,344	$1,460	$1,095	$530	$708
Simple payback	7.5	10	6.3	8.5	7.6	10.1	6.6	8.8

1 Assumes 25% savings
2 Assumes 15% savings
3 Based on single zone retrofit

APPENDIX A

TPS Steam to HW Conversion
SPECIFICATION AND PRICE GUIDE

BOILER CONVERSION

. CONVERT EXISTING BOILER TO HOT WATER

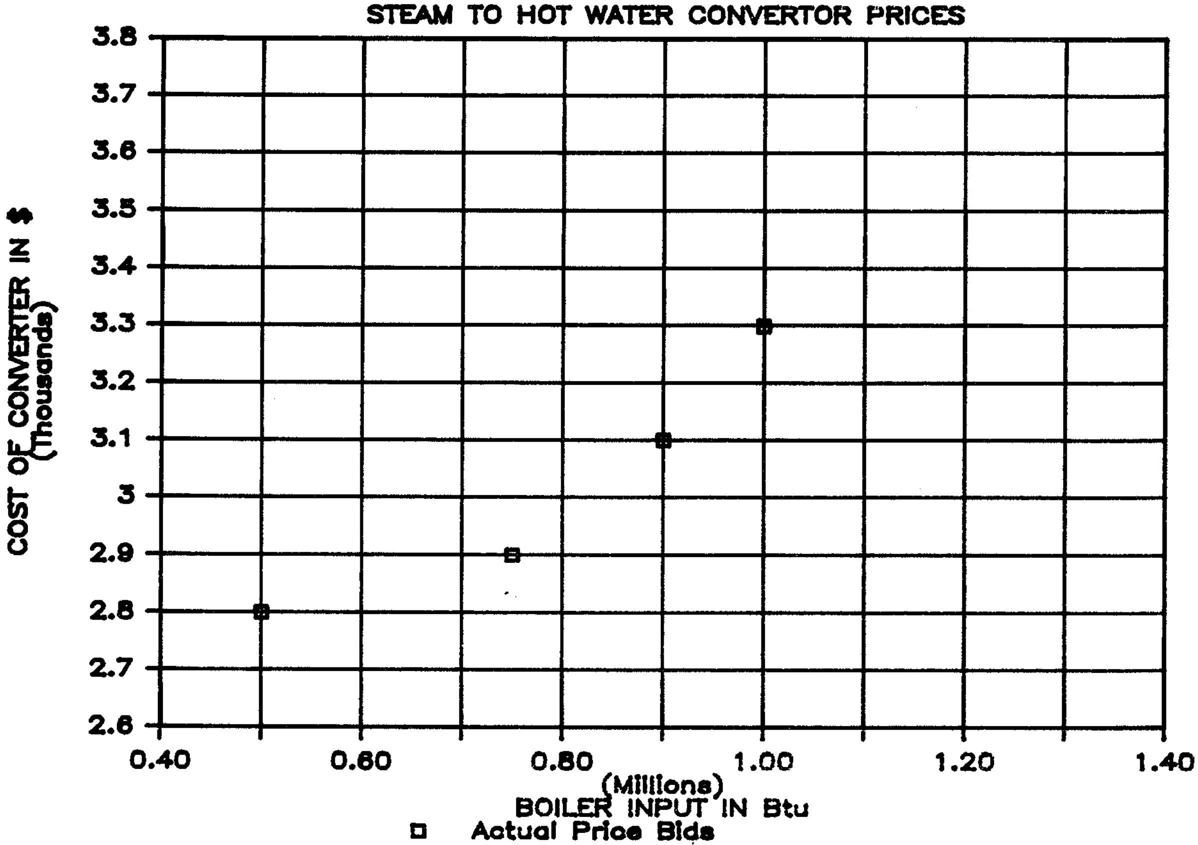
$ 1100	Normal Conversion Procedures
$ 200	Install Low Water Cut Out
$ 300	Clean, Tune Boiler
$ 300	Install Electric Vent Damper 12" of less diameter
$ 900	Install Electric Vent Damper larger than 12" dia.
$ 100	Install Thermal Vent Damper (3" - 8") diameter
$300-3000	Repair/Replace Steel Fire Tubes if leaking

$ 100	Repair (Reroll) up to four tubes
$ 200	Replace each tube if less than four
$100-150	Replace each tube if more than four
$ 3000	Replace all tubes in a boiler

. INSTALL STEAM TO HOT WATER CONVERTOR

$ 2800	500,000 input/ 400,000 output Boiler
$ 2900	750,000 input/ 600,000 output Boiler
$ 3100	900,000 input/ 720,000 output Boiler
$ 3300	1,000,000 input/ 880,000 output Boiler

STEAM TO HOT WATER CONVERTOR PRICES



. REPLACE BOILER

$5000-6000	Add FEMB htg only	150,000 Btu input each
$6500-8000	Add FEMB htg & DHW	150,000 Btu input each
$ 3500		Install new Boiler @ 300,000 Btu input each
$ 4500		Install new Boiler @ 400,000 Btu input each
$ 5000		Install new Boiler @ 500,000 Btu input each
$ 5500		Install new Boiler @ 600,000 Btu input each
$ 500		Add-on for removal of SFT or Large CI Boiler

BUILDING CONVERSION

. INSTALL PUMPS

$ 1100	One Pump
$ 1950	Two Pumps

. MISC. PLUMBING

$ 200	Average for misc. piping work & removing traps
$ 500	Replumb wet return as dry - one side of building
$ 1000	Replumb wet return as dry - both sides of building

. INSTALL ZONE VALVES

$ 600	1", 1.5", 2"	Zone valve w/ end switch & linkage
$ 1000	2.5", 3"	Zone valve w/ end switch & linkage
$ 1400	4"	Zone valve w/ end switch & linkage
$ 2800	5", 6"	Zone valve w/ end switch & linkage

RADIATOR CONVERSION

$ 65	Each- **repack** valve, remove trap & install bleeder
$ 100	Each- **replace** valve, remove trap & install bleeder
$ 130	Each- **replace w/TRV**, remove trap & install bleeder
$ 20	Each- repair broken valve
$ 45	Add-on per radiator if built-in or inaccessible

CONVERSION CONTROLS

$ 435	Thermostat- one stage, one remote sensor, operates boiler, pump, valve or combination
$ 500	Thermostat- one stage, two remote sensor, operates boiler,pump, valve or combination
$ 400	On/Off reset and cutout
$ 2400	3 way mixing value w/reset and cutout

NOTE: All prices assume installation as part of a larger project and are not accurate for estimating individual retrofits.