MULTIFAMILY PERFORMANCE PROGRAM

Case Study – Existing Buildings

Steam Boiler System Replacements

An anecdotal report of high energy savings at a 12-unit apartment building, resulting from the replacement of an old steam boiler with a new hot water (hydronic) boiler, led to a survey of similar completed projects to assess whether these high savings have been delivered elsewhere. Four projects were identified in which old steam boilers were replaced with new hydronic boilers. Savings were significant for all four, averaging 40.5% of total heating usage, far exceeding predicted average savings. By comparison, three projects were also identified for which old steam boilers were replaced with new steam boilers. Savings were extremely poor, averaging only 0.6% of total heating usage, falling far short of predicted average savings.

Heating System Characteristics in NY State Multifamily Buildings

Steam heating systems represent the vast majority of heating systems participating in the NYSERDA Multifamily Performance Program for existing buildings. A survey of 63 arbitrarily-selected buildings in the program found 46 (73%) to be heated with steam boilers, and six additional buildings (9.5%) heated with purchased steam, for a total of 82.5% of the buildings heated with steam. Of these 52 steam-heated buildings, 32 have 2-pipe distribution (62% of steam-heated buildings) and 10 have 1-pipe distribution (19% of steam-heated buildings). Most of these buildings are 20 years older or more, but the tradition of steam heat is so strong, that even relatively new buildings, as recent as five years old, have been found to be designed and built with steam boilers.

Of the steam-heated buildings, ten (19% of the steam-heated buildings) have steam primarily limited to the mechanical room. Their distribution systems are in fact hydronic, through the use of steam-to-water heat exchangers, generally referred to as converters or generators, typically located in the mechanical room. These represent opportunities for converting steam to hydronic within the boiler room itself, primarily by replacing the boiler. A water-to-water heat exchanger can be used in place of a steam-to-hot water heat exchanger in buildings where the distribution system head is a concern.

In surveying these buildings, it was found that the source energy use intensity in steam-heated buildings averaged 159.4 kBtu/SF-year, 24% higher than the 128.6 average for buildings not heated with steam.

Case Study Buildings

Pre-retrofit and post-retrofit utility bills were analyzed for seven buildings where old steam boilers were replaced. Other than having utility bills available and having had a steam boiler replaced, the buildings were arbitrarily selected. Six of the seven had participated in a NYSERDA program (AMP, ResTech, or MPP). Three buildings had old steam boilers replaced with new steam boilers, and four buildings had old steam boilers replaced with new hydronic boilers. The boiler replacements occurred in the period between 1996 and 2008. Summary characteristics of the buildings are shown in Table 1.

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	Steam-to-Steam			Steam-to-Hydronic			
Building	S2S-1	S2S-2	S2S-3	S2H-1	S2H-2	S2H-3	S2H-4
Stories	6	5	10	12	11	3	3
Apartments	54	10	80	361	116	12	656
Number of buildings	1	1	1	1	1	1	76
Type	Market Rate	Assisted	Market Rate	Market Rate	Market Rate	Market Rate	Assisted

Table 1: Building Characteristics

Heating characteristics of the case study buildings are shown in Table 2.

	Steam-to-Steam			Steam-to-Hydronic			
Building	S2S-1	S2S-2	S2S-3	S2H-1	S2H-2	S2H-3	S2H-4
Fuel, pre-retrofit	#4 oil	#2 oil	#6 oil	Gas	Gas	Gas	Gas & coal
Fuel, post-retrofit	#2 oil	#2 oil	#6 oil	Gas	Gas	Gas	Gas
Distribution, pre-retrofit	2-pipe Steam	1-pipe Steam	2-pipe Steam	Hydronic	Hydronic	2-pipe Steam	2-pipe Steam
Distribution, post-retrofit	2-pipe Steam	1-pipe Steam	2-pipe Steam	Hydronic	Hydronic	Hydronic	Hydronic

Table 2: Heating Characteristics

Findings

Predicted and actual savings are shown in Table 3.

	Steam-to-Steam			Steam-to-Hydronic			
Building	S2S-1	S2S-2	S2S-3	S2H-1	S2H-2	S2H-3	S2H-4
Predicted Savings	6.8%	21.0%	6.0%	24.1%	16.7%	NA	52.0%
Actual Savings	-12.4%	4.1%	10.0%	41.2%	22.6%	49.8%	48.2%

Table 3: Heating Energy Savings
(negative savings indicates an increase in energy use)

Savings are shown as per cent of original heating use, not as a percent of fuel use. Baseload usage such as domestic hot water or gas appliance use was subtracted out before savings were calculated. Predicted savings were not available for site S2H-3 because this project did not have an energy audit. All actual pre-retrofit and post-retrofit heating usage is weather-normalized.

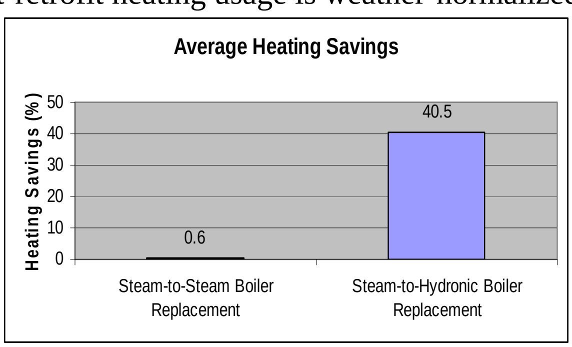

Figure 1: Comparative Heating Savings

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With some exceptions, non-boiler energy conservation measures (ECMs) were typically minor, or there were none at all. Where ECMs were implemented that interacted with the heating system, corrections were made to the savings calculations by assuming the non-boiler measures delivered savings according to the original energy audit. In most cases, since these projected savings were small or none relative to the boiler savings, the impact was small or none.

In two cases, however, buildings S2S-2 and S2H-4, the energy savings from envelope improvements were projected to be significant. For S2S-2, if the envelope improvements had delivered their full projected savings, the final results would have shown a net increase in heating energy use due to the boiler alone. To give the steam-to-steam boiler replacement the benefit of the doubt, it was assumed that the envelope improvements only delivered 33% of their projected savings, attributing the remainder of the savings to the boiler replacement. Savings were still only 4.1% of the original heating energy usage. Similarly, for the other two steam-to-steam sites, assumptions were made to give the boiler replacement the benefit of the doubt in calculating savings. For example, site S2S-3 was missing a post-retrofit May fuel oil delivery, and the June delivery data was not available, so it was assumed that no oil was in fact used between the April and June deliveries. Had less generous assumptions been made for the three steam-to-steam sites, results would have ranged from a 24.4% increase in heating usage to only a 2.4% savings, for a net average ***increase*** in fuel use as a result of replacing an old steam boiler with a new steam boiler.

Site S2H-4 also had substantial envelope improvements. Projected savings from envelope measures were fully subtracted from actual heating savings, and boiler-related savings still amounted to 48.4%. The example probably represents a worst-case scenario (best case for energy savings), as the boiler plant serves multiple buildings, and was known to have an old and leaky distribution system. Interestingly, a variety of other benefits were accrued from the conversion to a hydronic system: The improvement additionally saved high operations and maintenance costs due to the leaks, along with eliminating environmental concerns and liabilities related to the use of coal at the central plant.

Analysis

Actual savings (relative to annual heating use) from conversion to hydronic boilers are far higher (40.5% average) than savings from replacement with new steam boilers (0.6% average).

Actual savings from conversion to hydronic boilers (40.5% average) significantly exceed projected savings (31.0% average). Actual savings from replacing old steam boilers with new steam boilers (0.6% average) are significantly less than projected savings (11.3% average).

The two sites with the highest savings (S2H-3, at 49.8% savings, and S2H-4, at 48.2% savings) are the ones with a complete steam to hydronic conversion. In other words, the pre-retrofit distribution systems were steam, and the entire systems were converted to hydronic. At both sites S2H-3 and S2H-4, existing

2-pipe radiators were retained and re-used, as well as much of the existing piping. Condensate return piping was replaced in both buildings.

However, it is interesting to note that one site (S2H-1) had savings which were still substantial (41.2%), although its pre-retrofit distribution system was already hydronic. So substantial savings appears to be possible even with a pre-existing hydronic distribution system, where only the boiler is replaced.

Why are Steam Systems so Inefficient?

More exploration is needed to disaggregate the causes of steam inefficiencies, and fully explain why savings for conversion to hydronic heat are so high. However, it is known that:

a. Steam systems are hotter than hydronic, so conductive heat losses are higher.
b. Steam systems are open to the atmosphere, so there are venting losses. Steam system leaks can be less evident because steam can escape directly to the atmosphere rather than leaking as water. Conversely, hydronic system water leaks are often immediately evident.
c. New steam systems have lower efficiency limits than new hydronic systems. They also have limits to outdoor reset control: Hydronic systems can be run cooler during swing seasons.

To evaluate whether steam systems have higher water leak rates than hydronic systems, water usage for steam-heated buildings was compared to buildings without steam heat (hydronic, electric, or forced air), for a sample of buildings for which water usage and occupancy data was available. For ten steam-heated buildings, water usage averaged 162 gallons per person per day; whereas for nine buildings not heated with steam, water usage was found to be 76 gallons per person per day. The American Water Works Association (AWWA) estimates typical water usage to be 50-55 gallons per person per day. Average water usage at the ten steam-heated buildings is more than ***two times higher*** than at the buildings not heated with steam, and is clearly far higher than typical water usage estimated by AWWA. These findings are supported by data from two of the case study sites for which pre-retrofit and post-retrofit water usage is available. Site S2H-4 showed a 26% decrease in water usage after replacing a steam boiler system with a hydronic system. These savings are sufficient to increase overall cost savings by 17% for the project (when added to energy cost savings). By contrast, site S2H-1 only showed a 4% decrease in water usage after replacing a steam boiler with a new steam boiler. These results all consistently implicate steam leaks as a major component of the inefficiency of steam systems.

Reduced overheating and better system balance are other likely contributors to savings (see below).

Other Studies

Two prior studies also found high savings from converting steam heating systems to hot water. Lobenstein and Hewett[1] studied 10 buildings in Minnesota in the mid-1980's which had undergone a steam-to-hydronic conversion and found that single-pipe steam conversions saved between 13% and 27% of total weather normalized gas use, and two-pipe steam conversions saw savings of 17% to 39%. These savings figures are as a per cent of total gas use (including non-heating use), unlike the figures provided above which are as a per cent of fuel use for heating only. The savings relative to heating energy use for the Minnesota conversions likely fall within a very similar range as the 22.6%-49.8% range of the New York State findings above. A survey of building owners as part of the Minnesota study found, "Overwhelmingly, the owners and/or building managers reported a reduction in complaints from tenants regarding overheating or underheating of particular apartments," which points to better system balance as another component of energy savings of these conversions. In the two-pipe steam conversions, radiators and piping were retained and re-used in all projects.

A follow-up study of five more two-pipe conversions found energy savings ranging from 18% to 28%, with an average of 25% savings[2]. Again, savings are presented relative to total pre-retrofit gas usage. As a percentage of heating energy use, the savings appear to be in a similar range to the findings for the four steam-to-hydronic conversions which were evaluated in New York State. Since these projects are over 20 years old, cost savings and installed costs were far lower than today, but paybacks calculated for four of the five projects are informative: 5.6 years, 19.1 years, 7.2 years, and 5.3 years. The median payback was 6.6 years, and the average payback was 9.3 years. Paybacks do not include water savings, which were not evaluated.

Implications

Converting steam boilers to hydronic boilers represents a large opportunity for saving energy in New York State multifamily buildings. The simplest opportunity is where the existing distribution is already hydronic. Converting two-pipe systems can also be fairly straightforward, as radiators and piping can typically be re-used. However, whole-building steam replacements, where the entire distribution system needs to be replaced, should not be ruled out. The savings from converting to hot water appear to be so significant that the cost of replacing distribution systems may well be justifiable. Energy savings appear to be supplemented with significant water savings, due to the elimination of steam leaks and steam venting losses.

References

1. Converting Steam Heated Buildings to Hot Water Heat: Practices, Mary Sue Lobenstein and Martha J. Hewett, July 1986.
2. Converting Two Pipe Steam Heated Buildings to Hot Water Heat: Measured Savings and Field Experience, Mary Sue Lobenstein and Timothy S. Dunsworth, September 1989.

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