EFFECTIVENESS OF BOILER CONTROL RETROFITS ON SMALL MULTIFAMILY BUILDINGS IN WISCONSIN

Glenna Ewing and Don Neumeyer,
Wisconsin Power & Light Company,
Scott Pigg and Jeffrey Schlegel,
Wisconsin Energy Conservation Corporation

INTRODUCTION

Wisconsin Power & Light Company's (WP&L) Multifamily Research Project is designed to assess the efficacy of installing outdoor reset and cutout controls together with cleaning and tune-up work on hydronically heated multifamily buildings in WP&L's service territory. An outdoor reset is a device that controls boiler water temperature inversely with outdoor temperature: as outdoor temperature rises, the reset lowers boiler water temperature. A cutout shuts off the boiler burners when the outdoor temperature exceeds a pre-set level. A previous study (Hewett and Peterson, 1984) demonstrated annual space heating savings of 10 to 26% for the installation of resets and cutouts (without cleaning and tune-up work) in modern apartment buildings of 12-45 units in Minneapolis. A preliminary survey of apartment buildings in WP&L's service territory, however, showed that most apartment buildings are both smaller (4-8 units) and generally older (with an average age of 59 years) than those of the Minneapolis study. Moreover, it was felt that a better assessment of the effect of the retrofits on heating system performance and indoor temperature could be made if the buildings were more extensively monitored for indoor and outdoor temperature.

Accordingly, remote data acquisition systems (RDAS's) were installed in the fall of 1986 in seven apartment buildings, which ranged in size from 4 to 24 units. Each RDAS monitored boiler runtime, boiler water supply and return temperatures, outdoor air temperature, and a representative sample of indoor apartment temperatures. In all buildings, at least 50% of the apartments were monitored. The RDAS's scanned each sensor once every 3-5 seconds, and the data were recorded as hourly average temperatures and percent runtime. Runtimes were converted to actual gas consumption using master-meter calibrations.

The buildings are summarized in Table I. All of the buildings had hydronic heating systems with gas-designed cast iron boilers. All but one (#7) of the heating systems were controlled with aquastats to maintain constant boiler water temperature. The systems were configured, however, in several different ways. Two of the sites (#5 and #11) operated with continuous water circulation in a main distribution loop, with heat flow to the individual apartments controlled by zone valves. Several other sites (#2, #3 and #4) were configured in a similar fashion, except that water in the main distribution line only circulated when one or more zone valves were open. Sites #1 and #9 had individual circulation pumps for each heating zone. There was no main distribution loop in these buildings. Site #7 operated with individual circulation pumps for each zone, but (in the first pre-retrofit period) water circulated continuously through one zone, with the thermostat for this zone controlling the gas valve for the burners.

One 8-unit building had side-by-side identical boilers servicing 4 units each; one of the boilers (#2) received the tune-up work and reset/cutout retrofit, while the other (#3) received no work. All other buildings received tune-up work and had resets and cutouts installed.

Because contractors often have different ideas of what constitutes a "tune-up", a standardized procedure was developed that included:

- Cleaning of orifices, heat exchanger sections, flues, and combustion area.
- Instrumented tune-up of gas input and combustion air to achieve highest possible steady-state efficiency.
- Checking all safety switches and valves.
- Measuring pre and post-service steady-state combustion efficiency.

The resets were the "temp-sum" type, which maintain a constant sum of outdoor and boiler water temperature. The resets operated with a 1:1 reset ratio. Because the contractors were generally unfamiliar with the electronic controls, they were trained to install them properly.

After a period of pre-retrofit performance monitoring, the retrofit work was performed in February and March, 1987. Post-retrofit monitoring was done through the end of May, 1987, and continued in the 1987-88 heating season through the end of February. Because the pre-retrofit monitoring period did not provide an adequate picture of the warm-weather performance of the heating systems, the resets and cutouts were turned off, and the aquastats were set to the pre-retrofit settings; the sites were monitored in this fashion from mid-April through the end of May, 1988. Gas consumption data from this period were adjusted to account for changes in the steady-state efficiency resulting from the tune-up work.

ANALYSIS

The data indicated that a linear model of gas consumption versus indoor minus outdoor temperature (delta T) could adequately model the performance of the heating systems (Figure 1: site #1 is used here as an illustration of a typical site). To reduce the amount of scatter in the data due to system cycling, the analysis was performed on daily averages of gas consumption and delta temperature. Above a certain delta T, gas consumption rises linearly with delta T; below the pivot delta T, gas consumption is relatively constant. In the pre-retrofit period, the pivot delta T reflects the balance point delta T for the building. For the post-retrofit period, the pivot delta T represents a combination of the building balance point and the point beyond which the cutout control holds the boiler off. The best pivot delta T was found for the pre and post-retrofit data for each building by successively regressing the data using pivot delta T values from 0 to 20 F°, and choosing the one that had the highest correlation.

Apartment temperatures from the heating season data were analyzed by binning the hourly overall average indoor temperature in 1 F° bins by outdoor temperature (Figure 2). Averages and confidence limits for each bin were then calculated. Overall average pre and post-retrofit indoor temperatures were analyzed by binning individual apartment temperatures in 5 F° bins of outdoor temperature, and then calculating bin and overall averages. To calculate the overall average indoor temperature, each bin was weighted by the normal frequency of occurrence of outdoor temperature for Madison, Wis., for the months of October through May (Air Force, 1978).

Pre and post-retrofit normalized annual heating consumption (NAHC) estimates were calculated using the Air Force frequency distribution of outdoor temperature for Madison. The midpoint temperature of each bin was converted to an equivalent average delta temperature for the building, and hourly gas consumption at that temperature was calculated using the regression equations discussed above. The total gas consumption for each bin was found as the product of the hourly consumption and the normal hours of occurrence of temperatures within the bin. The total seasonal gas consumption was found by summing all the bins (Figure 3).

RESULTS

Analysis of the pre and post-retrofit steady-state combustion efficiencies (SSE) showed minimal improvement as a result of the cleaning and tune-up work (Table I). Three of the eight systems actually had a slight drop in SSE. The largest improvement in SSE (from 69.5% to 77.8%) was seen at site #7, which also had the lowest pre-retrofit SSE. Most of the sites, though, were already operating at fairly high SSE's before the retrofit work was done: thus, the average pre and post-retrofit SSE's of all the sites taken together changed by less than 1% from the pre-retrofit value of 76.7%. It appears, therefore, that the cleaning and tune-up work did not contribute significantly to the energy savings.

Annual energy savings estimates ranged from -1.2% to 14.8% for the 6 systems that received properly-functioning retrofits (Table 1). The average savings for these sites was 7.3%, or 321 ccf/year. Aside from site #5 (where the reset was later found not to be operating correctly), site #7 shows the lowest savings. Although the confidence limits of NAHC for this site suggest that the negative savings are not statistically significant, the lack of greater savings at this site probably resulted from the anomalous way that the heating system operated in the pre-retrofit period. The effect of a single thermostat controlling the boiler gas valve is somewhat like the action of a reset: as outdoor temperature rises, there are fewer calls for heat from the thermostat, and boiler water temperature is maintained at a lower average temperature. Large savings would not be anticipated at this site.

The highest savings, in both relative (14.8%) and absolute (1005 ccf/year) terms, were obtained at site #11, where the large size of the boiler and the fact that it operated in a continuous-circulation manner made it a good candidate for the reset and cutout retrofits.

On average, the total retrofit work and materials cost $445. Of this, an average of $91 (with a range of $22 to $198) was spent on the cleaning and tune-up work. Economic savings from the retrofits ranged from 10.0% to 135% return on investment for those sites that showed positive savings. Simple payback periods ranged from 0.7 to 7.6 years for these sites. The average simple payback for the six sites with properly functioning retrofits taken together was 2.7 years.

Analysis of overall average indoor temperatures (weighted by frequency of outdoor temperature) showed that the buildings were kept at a relatively warm level (69.5 to 75.3 °F). Changes in indoor temperature between the pre and post-retrofit periods were statistically significant, but rather trivial in terms of indoor comfort. At all but one site (#7), the indoor temperature was actually slightly warmer in the post-retrofit period compared to the pre-retrofit period. The average temperature rise for all of the buildings taken together was 0.7 F° (from 71.9 to 72.6 °F). There was a tendency toward higher space temperatures when it was very cold outside (-20 to 0 °F). This may have arisen because the aquastat settings were generally increased when the retrofits were installed so that they would function as high-end limits for boiler water temperature. Only one site (#11) showed statistically significant lower indoor temperatures during warm periods (i.e. greater than 60 °F). In fact, this site showed a statistically significant indoor temperature reduction down to an outdoor temperature of about 40 °F. Indoor temperature changes in the region of greatest energy savings (15 to 40 °F) were generally either statistically insignificant or trivial (less than 1 F°).

A pictorial summary of the conclusions of this study can be seen in Figure 4, in which the change in average indoor temperature between the pre and post-retrofit periods is superimposed on the estimated annual heating energy savings over the range of outdoor temperatures. Energy savings from outdoor resets and cutouts in small multifamily buildings are evident when the controls are installed properly and function correctly, but the savings do not come at the expense of indoor comfort. Rather, the data seem to indicate that they result from increased distribution efficiency and reduced off-cycle losses.

A more detailed report of this study is available from Wisconsin Power & Light Company (Pigg and Schlegel, 1988).

REFERENCES

Air Force, Engineering Weather Data, Manual 88-29, 1978.

Martha Hewett and George Peterson, "Measured Energy Savings from Outdoor Resets in Modern, Hydronically Heated Apartment Buildings," Proceedings of ACEEE 1984 Summer Study on Energy Efficiency in Buildings, Vol. C, pp. 135-152, 1984.

Scott Pigg and Jeffrey Schlegel, "Effectiveness of Boiler Control Retrofits on Small Multifamily Buildings in Wisconsin," Wisconsin Power & Light Company, (forthcoming) 1988.

Table I. Summary of sites and results.

SITE:	#1	#2[1]	#3[1,2]	#4	#5[3]	#7	#9	#11	AVG.
NUMBER OF UNITS	8	4	4	4	24	9	4	12	8.6
NUMBER OF CIRCULATION PUMPS	8	1	1	1	1	9	4	1	
NUMBER OF ZONE VALVES	0	5	5	4	24	0	0	12	
CONSTANT CIRCULATION	NO	NO	NO	NO	YES	NO[4]	NO	YES	
PRE-RETROFIT AQUASTAT SETTING [F°]	160	172	160	180	195	187[5]	160	180	174
RESET SETTING[6] [F°]	160[7]	160		160	190	160	160	160	164
CUTOUT SETTING [F°]	60	60		60	80	60[8]	70	60	64.3
STEADY-STATE COMBUSTION EFFICIENCY									
PRE-RETROFIT	76.7%	80.9%	82.4%	73.5%	72.5%	69.5%	81.2%	76.9%	76.7%
POST-RETROFIT	76.3%	78.4%	79.0%	74.2%	72.8%	77.8%	82.7%	79.2%	77.6%
AVERAGE INDOOR TEMPERATURE[9] [F°]									
PRE-RETROFIT	72.2	69.5	71.3	72.0	73.8	71.4	71.6	73.7	71.9
POST-RETROFIT	72.3	69.8	72.4	74.0	75.3	70.3	72.3	74.5	72.6
ESTIMATED NAHC [ccf/year]									
PRE-RETROFIT	4169	2132	1459	2163	9042	7471	3492	6803	4592
[lower 95% confidence limit]	4046	2018	1395	2084	8672	7241	3418	6687	4445
[upper 95% confidence limit]	4292	2247	1524	2242	9412	7702	3567	6919	4738
[regression r^2]	.925	.832	.870	.950	.913	.952	.966	.946	.919
POST-RETROFIT	3739	1938	1568	2079	9406	7561	3188	5799	4410
[lower 95% confidence limit]	3629	1893	1523	2014	9179	7344	3118	5721	4303
[upper 95% confidence limit]	3855	1984	1613	2151	9633	7788	3267	5876	4521
[regression r^2]	.943	.970	.899	.969	.964	.972	.977	.987	.960
SAVINGS [ccf/year]	430	194	-109	84	-364	-90	304	1005	321[10]
[%]	10.3%	9.1%	-7.4%	3.9%	-4.0%	-1.2%	8.7%	14.8%	7.3%[11]
[$/year]	$219	$99	($55)	$43	($186)	($46)	$155	$512	$164[11]
INSTALLED COST [$]	$460	$570	$0	$326	$450	$355	$574	$380	$445[12]
BENEFIT/COST RATIO	4.94	1.81		1.36	-4.28	-1.34	2.80	14.01	3.83[11]
RETURN ON INVESTMENT	47.5%	15.3%		10.0%		---	26.2%	135%	36.5%[11]
SIMPLE PAYBACK PERIOD [YRS]	2.1	5.8		7.6		---	3.7	0.7	2.7[11]

[1]Side-by-side boilers in the same building.
[2]No retrofit work done on this boiler.
[3]Reset did not function properly at this site.
[4]Constant circulation in one zone during pre-retrofit period (see text).
[5]Set at 125 °F in second monitoring period.
[6]Sum of outdoor and boiler water temperature.
[7]Later turned up to 190 °F.
[8]Later turned up to 100 °F.
[9]Weighted by normal frequency of occurrence of outdoor temperature.
[10]Does not include site #3 or site #5.
[11]Result of six sites taken together. Does not include sites #3 and #5.
[12]Does not include site #3.

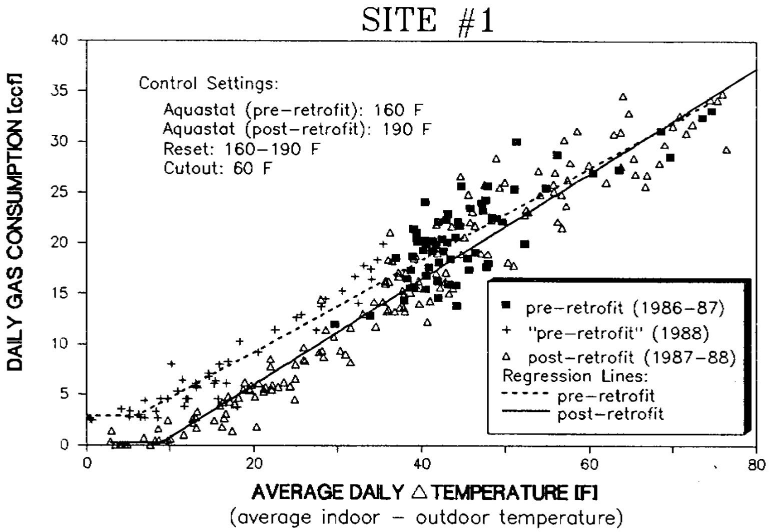

Figure 1. Regression fit of gas consumption to average daily delta T.

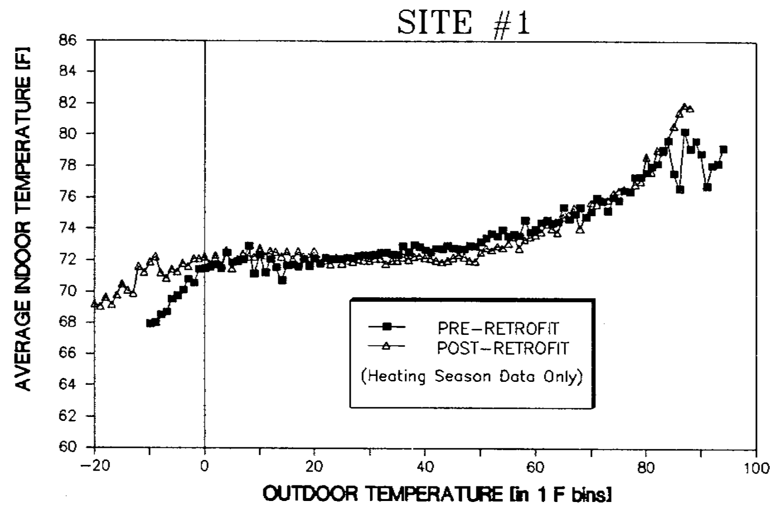

Figure 2. Pre and post-retrofit average indoor temperature vs. outdoor temperature.

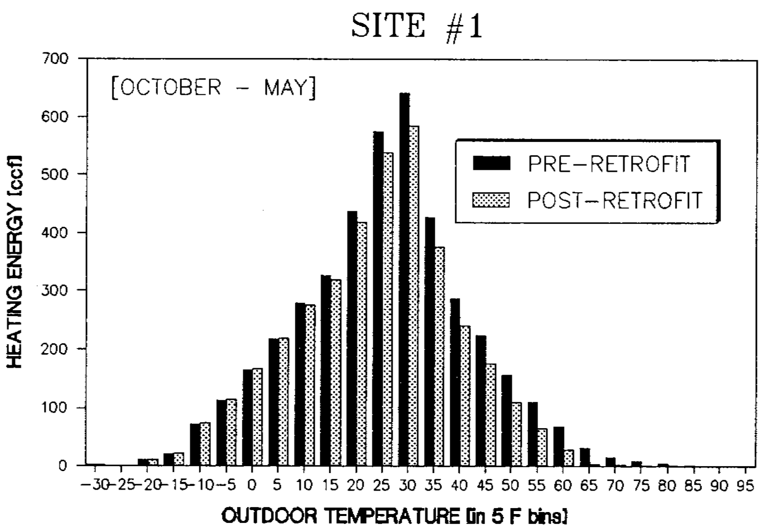

Figure 3. Distribution of normalized heating energy by outdoor temperature.

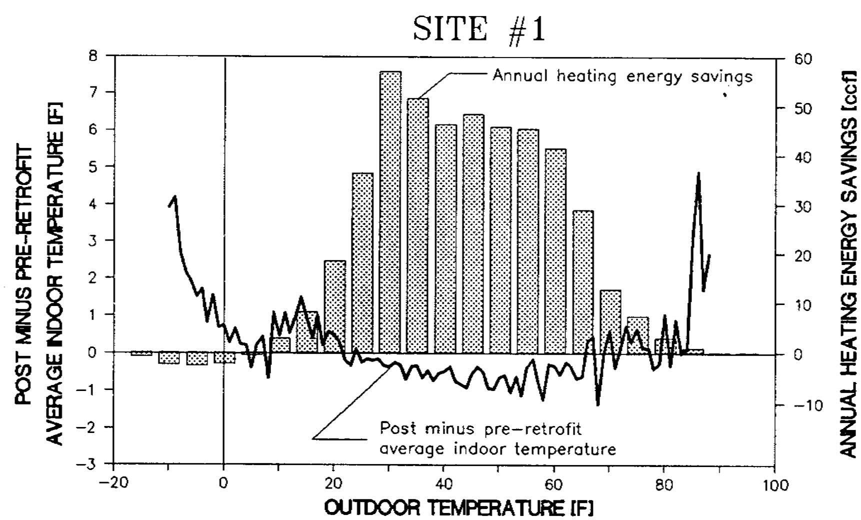

Figure 4. Energy savings and change in average indoor temperature vs. outdoor temperature.