92.028

Prepared by:
Proctor Engineering Group, Ltd.
San Rafael, CA 94901
(415) 451-2480

LOW COST BOILER EFFICIENCY IMPROVEMENTS

Presented at:
1984 ACEEE Summer Study on Efficiency
in Buildings Conference

Final Report
August, 1984

Author:
John Proctor, P.E.

Creators of CheckMe!®

LOW COST BOILER EFFICIENCY IMPROVEMENTS

John Proctor
Sun Power Consumer Association
Denver, Colorado

ABSTRACT

In this paper, boiler efficiency work in 46 households is studied. Most of the work was done as part of the Colorado Office of Energy Conservation Weatherization Program funded by LIEAP. The units in this study are single family residences with natural gas fired boilers. The procedures and treatments described can also be applied to propane and oil fired units.

The paper consists of two sections, the first deals with the technical details of the program including boiler controls, combustion and distribution efficiency improvements as well as essential administrative components of feedback, training and control. The second section deals with the evaluation method, results and conclusions.

The Boiler Program savings exceed the low cost furnace efficiency program results. The average annual gas heating bill for this group of homes was $786. The Boiler Program alone saves about 13.7% of that, or $107 per year. The average per unit cost of the efficiency work (parts, labor, and administration) is $198. This results in a payback on the efficiency items of 1.85 years.

INTRODUCTION

A low cost heating system efficiency improvement system was pioneered in the summer of 1982. That program showed a 12% heating savings. Details of that program are described in the 1984 and 1986 ACEEE papers, "Low Cost Furnace Efficiency Improvements" (Proctor, 1984) and "Low Cost Furnace Efficiency Program - 10,000 Furnaces Later" (Proctor, 1986). Analysis of the first year's data showed the two boilers in the program resulted in 10% and 28% savings. The Boiler Program procedures were subsequently formalized and used in two locations (Colorado Springs and Denver). The units in this study are single family residences with natural gas fired boilers. The procedures and treatments described can also be applied to propane and oil fired units.

The first section of this paper deals with the technical details of the program including boiler controls, combustion and distribution efficiency improvements as well as essential administrative components of feedback, training and control. The second section deals with the evaluation method, results and conclusions.

PROGRAM DETAILS

Selection of Program Components

While many possible program components were considered for this program, the items which seemed the most likely to provide high savings at relatively low costs were:

Hot Water Control Systems. Unfortunately in residential heating systems the boiler water is often controlled at about 190°F. Generally a lower temperature will adequately heat at a lower cost. A lower boiler water temperature increases steady state efficiency, reduces off cycle losses and distribution loss. A number of control systems are charted below at identical partial loads.

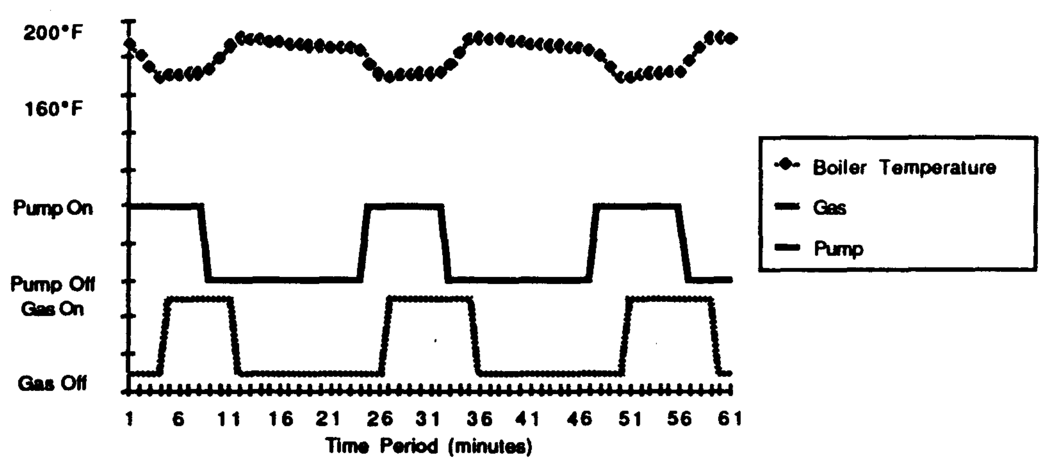

Figure 1. Constant Temperature Boiler Operation

Constant temperature boiler operation is the least efficient and most costly system. It uses fuel to keep the boiler temperature at the limit temperature regardless of the demand on the system, even in the summer.

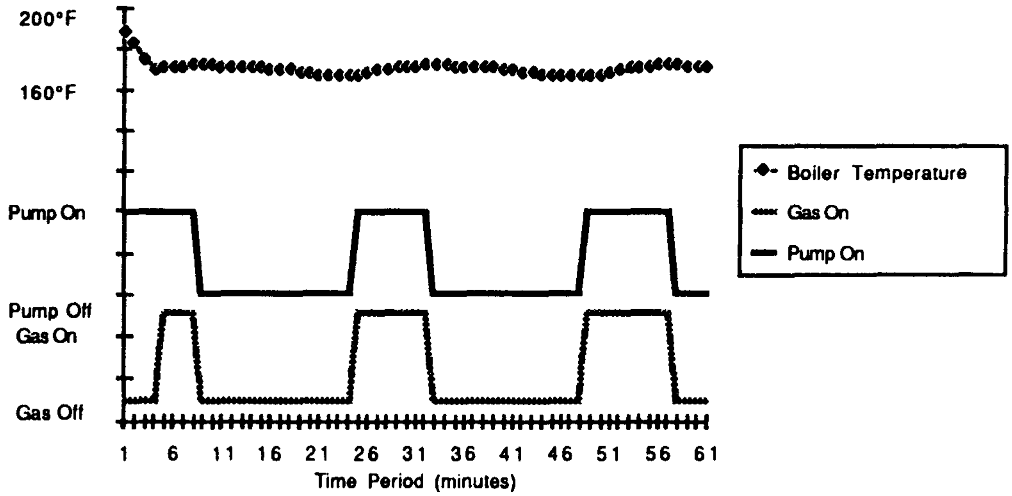

Figure 2. Single Control Thermostat Operation

The single control thermostat is the most common system. The thermostat turns on both the circulating pump and the boiler burners. This results in the boiler water temperature being kept near the limit in all but the mildest conditions (as shown in Figure 2). This system is an improvement over having a constant boiler water temperature, but far from optimum.

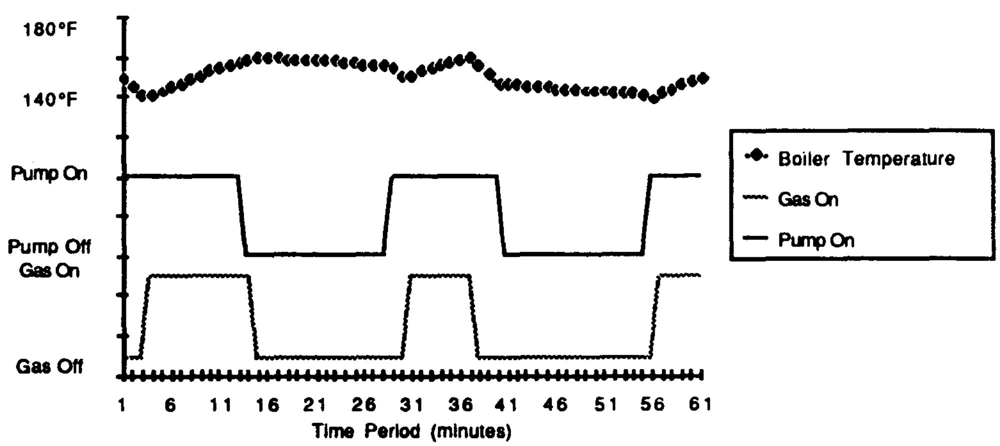

Figure 3. Outdoor Reset Operation

The outdoor reset with a cut-out works well for multiple unit apartment buildings. It varies the boiler water temperature with the outdoor temperature (raising boiler temperature as outside temperature drops). It also shuts down boiler when it is warm outside. The primary drawback to this type of control is that the the reset rate and base water temperature must be set correctly in order to achieve the maximum savings. This leads to substantial fiddling and less than optimum performance. Generally the outdoor reset will save 6% to 15% over the single control thermostat. The cost is about $300.

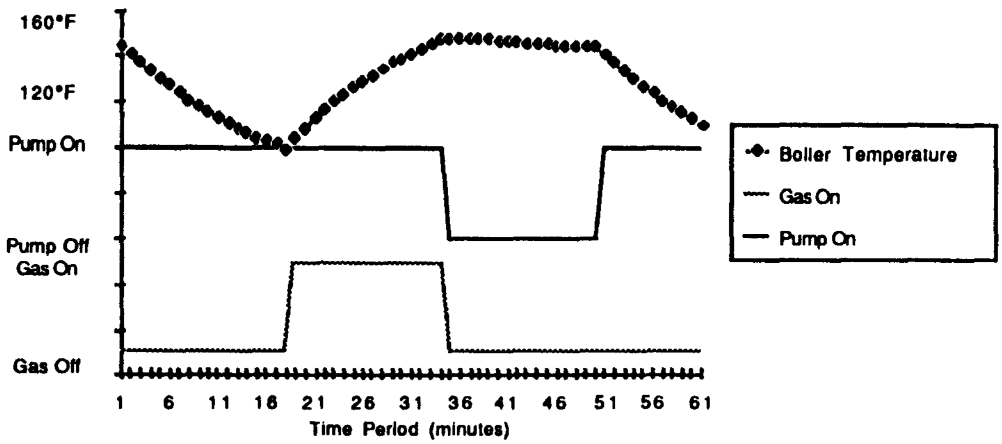

Figure 4. Denver Boiler Time Delay Operation

The Denver Boiler Time Delay (DBTB) works well in houses with one or more zones. It varies the boiler water temperature based on total system demand (note that demand is made up of more than outside temperature - setbacks substantially effect demand). As shown in Figure 4, this is accomplished by first circulating boiler water without turning on the burners. The burners only go on if additional heat is required. This maintains the boiler at a lower average temperature and reduces total burner on time. If the boiler cycles off on the limit, the time delay is again activated effectively derating the boiler. This costs about $25 in materials and 30 minutes to accomplish. The annual savings is 8% to 18% over a single control thermostat system.

The Denver Boiler Time Delay (DBTD) is an outgrowth of the dual stage thermostat system tested and reported on by the Hydronics Institute (1965). The dual stage thermostat system uses the first stage to control the pump. Thus the pump runs immediately upon a call for heat. The gas comes on only when the room temperature drops further to activate the second stage. Their tests predicted a savings of 25 to 30%. The major drawback to the dual stage system is the cost. It costs about $100 for the thermostat (in some zoned systems one is necessary for each zone). In addition the wiring of the system is relatively complex.

We have tested both the dual stage and the time delay. They both seem to work well under most circumstances. In one case (Unit 34), we first installed the dual stage system, insulated the pipes and removed a convector in the crawlspace. The resulting savings was 36% After two years of operation and monitoring the dual stage was removed and a DBTD was installed. The resultant additional savings over the dual stage was 3%. In another case, one of twenty three installations, the DBTD system was unable to meet the heating demand at design temperature. In this case the boiler was sized very close to the actual demand of the structure. The question still remains whether the reduced boiler water temperature in warm weather will cause condensation on the fire side of the water jacket and reduce boiler life. There has been no evidence of corrosion in the boilers we have seen after the DBTD or the dual stage systems were operational.

Control system changes contribute substantially to the savings of the program. Figure 5 shows the average boiler water temperature using various control strategies under different loads.

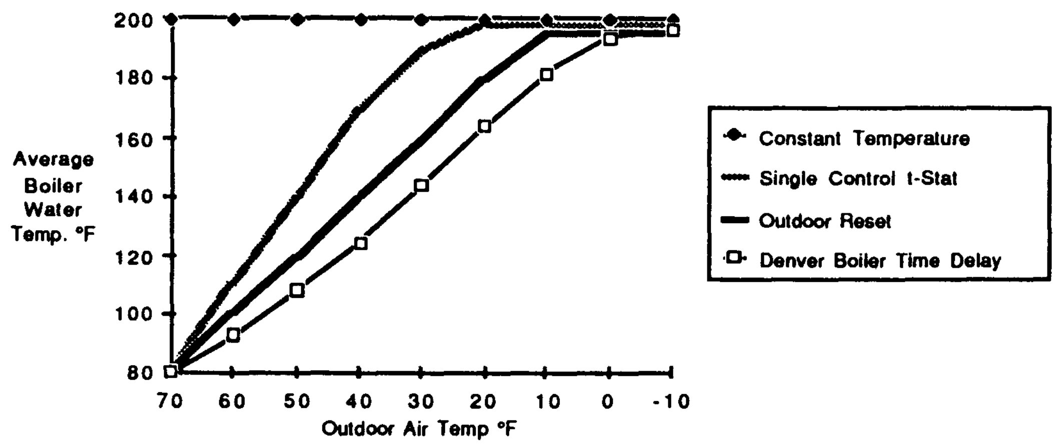

Figure 5. Effect of Control System Strategies

Distribution Systems. In both steam and hot water systems, leaks and uninsulated piping can be the source of major losses. Leaks are repaired and all accessible distribution piping is insulated. Uneven distribution caused by malfunctioning valves and vents is also corrected.

Steady State Efficiency Adjustments. In conversion boilers (converted from coal to natural gas) our tests have found the steady state efficiency to average around 69%. Others have suggested that the solution to this problem is to retrofit with a power burner. We have found it less costly and equally effective to clean the heat exchanger, install turbulaters in the form of refractory brick, and adjust the supply of primary and secondary air. The results as shown in Table 1 are very satisfactory. The process must be done with the appropriate tools (flue gas analyzer, flue gas thermometer, and carbon monoxide detector) to insure adequate results.

Table 1. Steady State Efficiency Change due to "Bricking" and Fuel Air Adjustments

Unit	Eff. before	Eff. after	Type
Client #11	76.5%	79.9%	Gravity Water
Client #15	68.0%	78.4%	Gravity Water
Client #26	66.5%	79.5%	Gravity Water
Client #28	65.0%	77.3%	Old Steam
Client #30	69.0%	80.25%	Gravity Water
Client #31	74.0%	80.0%	Forced Circulation
Client #32	64.0%	80.3%	Old Forced Circulation
Average	69.0%	79.4%	

Oil fired units could achieve similar savings through the use of retention head burner or retention head retrofits.

Administrative Considerations

The administrative aspect is often the least appreciated and most overlooked part of a retrofit program. Without them the best technical package will result in only mediocre savings, high costs, administrative headaches, liability problems and possible unsafe conditions inside the clients homes. The administrative system described below is now used on three programs; the furnace program, the boiler program and the "House Nurse" program. The administration and training are detailed in the 1986 ACEE paper, "Low Cost Furnace Efficiency Program - 10,000 Furnaces Later" (Proctor 1986). While we will not repeat the information here it is absolutely essential that long term training and control be utilized to get and keep the program on track.

Administrative Structure. The administrative structure is diagramed in Figure #6.

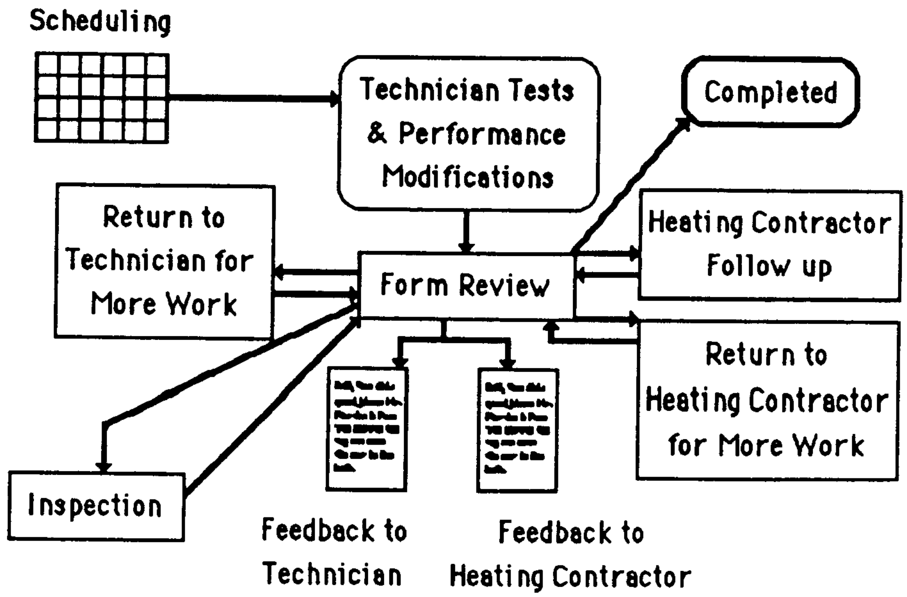

Figure 6. Methodology of Program Delivery

Initially a technician visits the house and uses a "cook book" form. This insures that all the items are completed. In the course of her approximately 4 hours at the location the technician completes a large portion of the necessary work including:

1. Entry interview.

   a. Any heating problems known to the client.
   b. What will be accomplished in the visit.
   c. Cycle the boiler to insure it works properly before work begins.

2. Efficiency and safety inspection, recording all data for later review by technical form reviewer.

   a. Check for gas leaks.
   b. Check for boiler water jacket leaks.
   c. Check draft.
   d. Determine type of boiler.
   e. Determine type of control system.
   f. Check for correct flow pattern and distribution.
   g. Test for time delay necessary.
   h. Check for CO.

3. Work on the boiler based on the efficiency and safety inspection. All work done is recorded on the report form.

   a. Insulate pipes.
   b. Reset anticipator.
   c. Replace inoperable steam vents.
   d. Clean the heat exchanger on conversion units.
   e. Unclog flue.
   f. Repair steam leaks.
   g. Repair water leaks at valves.
   h. Bleed air out of lines radiator/convectors.
   i. Install Denver Boiler Time Delay and set to proper time.
   j. Oil pump.

4. Record final condition of boiler.

5. Conduct self help session with client regarding the boiler, teaching ways to maintain the efficiency of the system.

The supervisor/form reviewer sits down and does a 100% review of the initial data on the heating system, the work done on the appliance and the final condition of the system. This is accomplished <u>EVERY WEEK</u> through paperwork designed to speedily and accurately communicate those items to the form reviewer. This process includes automatic and absolute rules on repairing dangerous situations. At that time copies of the forms are marked with comments for the technician. These marked copies are delivered to the technician within one week of the initial work. Based on the forms and past performance the units for inspection are selected. Inspections are completed within two weeks of the work and written feedback is provided to the technician and heating contractor within that time.

The supervisor/form reviewer also decides what follow up work is to be done on these furnaces. Only work ordered by the supervisor is allowed.

After form review about 75% of the boilers require additional follow up by a <u>specially trained</u> heating contractor. This follow up includes repair or replacement of malfunctioning or broken pumps, gas valves, pressure relief valves, auto fill devices, low water cut offs, etc. It also includes testing and adjusting the fuel air ratio on conversion boilers as well as revising the combustion product flow path through the boiler heat exchanger. Hot water control systems, other than single control thermostat systems, are converted to the gas valve time delay device.

<u>Liability.</u> The primary argument used against training individuals to adequately deal with heating systems is that the liability risks are too high. Consider that weatherization attempts to reduce the number of air changes naturally occurring in the home. If that home has a flue that dumps combustion products into the home, (and our studies show that about 11% have that problem, Proctor, 1984) and the weatherization is successful, then the concentration of combustion products in the

home is increased. Does the agency not have a larger liability problem by not discovering and leaving a dangerous flue?

Attempting to deal with difficult situations by acting in an ostrich like manner does not guarantee that assumptions that you avoided dealing with will not come back to haunt you.

SAVINGS ANALYSIS

Data Acquisition

The files of three weatherization agencies were searched for units which had boilers. All of these agencies use the Sun Power boiler program. Because of the scarcity of boilers in this region, records for paying clients were also added. This resulted in a sample set of 46 units. The records were searched to determine if any other weatherization work was done on this unit. If other weatherization work was done the unit was analyzed in separate groups. There are a total of four groups: Group 1 - No other weatherization done, Group 2 - some caulking , weatherstripping or other air infiltration work done, Group 3 - air infiltration work plus attic insulation, Group 4 - infiltration work plus attic and wall insulation.

Clients were called to determine if weatherization work had been done that was not in the agencies records and whether there had been changes in thermostat settings or occupancy changes. There were 8 units dropped from the analysis due to those reasons.

Missing utility data was obtained from the local gas company. At that point 11 units were dropped due to shut offs, estimates and other lack of utility data. The resulting 27 units were analyzed by a method developed by Sun Power as a portion of the Sun Power Accelerated Monitoring Program (SPAM).

Analysis

The analysis technique starts with the same basic assumption as PRISM, that is, the heating fuel use can be modeled by the linear equation:

$$F = b \times T + c \times D_{bt}$$

Where:

F = The amount of fuel used in a particular time period in CCF,
b = The base amount of fuel used when there is no heating load in CCF/day,
T = The Time period between data points in days,
c = The amount of fuel used per Degree Day at the derived balance temperature (bt) in CCF/Degree Day,
D_{bt} = Degree Days calculated from the derived balance temperature in °F days,
bt = The balance temperature determined to give the best fit line.

home is increased. Does the agency not have a larger liability problem by not discovering and leaving a dangerous flue?

Attempting to deal with difficult situations by acting in an ostrich like manner does not guarantee that assumptions that you avoided dealing with will not come back to haunt you.

SAVINGS ANALYSIS

Data Acquisition

The files of three weatherization agencies were searched for units which had boilers. All of these agencies use the Sun Power boiler program. Because of the scarcity of boilers in this region, records for paying clients were also added. This resulted in a sample set of 46 units. The records were searched to determine if any other weatherization work was done on this unit. If other weatherization work was done the unit was analyzed in separate groups. There are a total of four groups: Group 1 - No other weatherization done, Group 2 - some caulking , weatherstripping or other air infiltration work done, Group 3 - air infiltration work plus attic insulation, Group 4 - infiltration work plus attic and wall insulation.

Clients were called to determine if weatherization work had been done that was not in the agencies records and whether there had been changes in thermostat settings or occupancy changes. There were 8 units dropped from the analysis due to those reasons.

Missing utility data was obtained from the local gas company. At that point 11 units were dropped due to shut offs, estimates and other lack of utility data. The resulting 27 units were analyzed by a method developed by Sun Power as a portion of the Sun Power Accelerated Monitoring Program (SPAM).

Analysis

The analysis technique starts with the same basic assumption as PRISM, that is, the heating fuel use can be modeled by the linear equation:

$$F = b \times T + c \times D_{bt}$$

Where:

F = The amount of fuel used in a particular time period in CCF,
b = The base amount of fuel used when there is no heating load in CCF/day,
T = The Time period between data points in days,
c = The amount of fuel used per Degree Day at the derived balance temperature (bt) in CCF/Degree Day,
D_{bt} = Degree Days calculated from the derived balance temperature in °F days,
bt = The balance temperature determined to give the best fit line.

This analysis proceeds through the following steps: First, the base use is determined from the summer use by dividing the CCF use by the number of days in the meter reading period. In this geographical section of Colorado there are almost two months when all but the most extravagant fuel users use no CCF for heat. Setting the base use fixes the Y intercept of the line, b, and leaves only the slope, c, and the balance temperature, bt, to be determined by best fit analysis. Second, using iteration, the best fit slope and balance temperature is determined. Third, the r2 is calculated to determine what percentage of the fuel usage is predictable (using this analysis) from the variation in daily average outdoor air temperature. Since the changes that we are looking for are sometimes small, we eliminated any units with an r^2 was less than .75. This resulted in the elimination of 4 units from the evaluation. Fourth, the normalized annual fuel use for heating ($NAFU_{heat}$) is determined by the equation:

$$NAFU_{heat} = c \times D_{bt\ avg.\ year}$$

Where $D_{bt\ avg.\ year}$ is the annual degree days at the derived balance temperature in an average year. Fifth, the annual base fuel use (AFU_{base}) is determined by the equation:

$$AFU_{base} = b \times 365.25 \text{ days}$$

Sixth, the normalized annual consumption is determined by the equation:

$$NAC = NAFU_{heat} + AFU_{base}$$

This is important to insure that anomalies in the summer fuel use do not effect the conclusions of the analysis.

The resulting analysis gives a closer approximation of the true heating slope and balance temperature for an individual house than an analysis that treats the base and heating use together. This is especially important when the sample set is small and we cannot depend on a large N to cancel out non- weather related changes.

Results

The above analysis on the remaining units in the sample is shown in Table 2.

Table 2. Savings by Group

Identification	Savings	N
Average Group 1 (No other weatherization)	13.7%	11
DBTD Only	12.4%	2
Steady State Modifications Only	15.6%	5
Other Combinations	11.9%	3
Average Group 2 (Additional infiltration work)	20.9%	5
Average Group 3 (Additional inf. and insul.)	34.2%	4
Average Group 4 (Even more insulation)	27.9%	3

Program Costs

The average per unit cost of these units is; Efficiency work (parts, labor, and administration) $198, Repair work $174. The repairs needed on boilers is substantially higher than what we have found on furnaces. This is due to the lack of maintenance of the units in low income dwellings. Boilers have a substantially longer lifetime than the average furnace and are therefore older as well. In spite of substantial repairs, we have not had to replace a boiler as of this date.

Cost Payback

The average annual gas heating bill for this group of homes was $786. The Boiler Program alone saves about 13.7% of that, or $107 per year. That results in a payback on the efficiency items of 1.85 years. If the necessary repair items are included the payback is 3.47 years.

Conclusions

Since most studies of low income weatherization programs show a savings of around 13% at a cost of $1200 to $1600, the cost effectiveness of the Boiler Program is substantially better.

While it is essential that the program include technically correct items, a major reason for the cost effectiveness is largely the result of the training, feedback, evaluation and controls.

The Denver Boiler Time Delay shows substantial promise as a technical option. It should be studied on a larger (say 100 unit) sample without any other changes to determine its true average savings and any possible side effects.

Altering the combustion product flow through old converted coal boilers coupled with adjusting the fuel air ratio has proven to be a low cost method of increasing the steady state efficiency of these units. Because of the low cost it is more cost effective than installation of power burners.

REFERENCES

Hydronics Institute (1965), "Controls for Zoned Hydronic Systems" Technical Topic #3A

Proctor (1984), John P. "Low Cost Furnace Efficiency Improvements" ACEEE Proceedings 1984

Proctor (1986), John P. "Low Cost Furnace Efficiency Program - 10,000 Furnaces Later" ACEEE Proceedings 1986

APPENDIX A

How To Install A Denver Boiler Time Delay

1) Determine the relationship between the storage mass and the amount of convection. Test the time required to "pull down" the boiler temperature from the limit temperature to 120°F (all zones calling for heat and the burner off). This number is the "pull down" time. If the time exceeds 17 minutes stop the test.

2) Determine if the system is utilizing standard controls. Check:

   a) Is this a millivolt system? (See special instructions for millivolt systems)
   b) Does this system have an outdoor reset control?
   c) Does the system have a controller labeled minimum or circulator and does lowering that control setting result in the pump turning on?
   d) With all thermostats set down as far as they go does raising the temperature of the high limit aquastat result in the burner coming on?

If the answer to all of the above is no, continue. If any answers to the above are yes, rewire to standard controls. Standard controls are defined as a system utilizing 24 volt control circuitry where a call for heat at the thermostat results in both the pump and the burner going on. The high limit aquastat is in circuit just before or after the gas valve. (SEE WIRING DIAGRAMS)

3) Turn off the main switch. Set the time delay at 1 minute and install the Denver Boiler Time Delay in one of the two wires to the high limit aquastat. This puts the DBTD in series with the high limit.

4) Reset the high limit to it's original setting and turn on the main switch. Turn up the thermostat. The pump should come on almost immediately and the burner 60 seconds later. If this unit has a time delay gas valve the time will be longer. If everything functions ok, turn off the main switch.

5) Set the time delay at the "pull down" time. If the "pull down" time exceeded 17 minutes, set it at 17 minutes. Turn the main switch back on.

APPENDIX B

Adjustments, Repairs and Replacements to Boilers

Seven boilers were treated in Colorado Springs under this program. The adjustments, repairs and replacements are listed here by % of occurrence.

Added gas valve time delay	85.7
Insulated delivery and return pipes	85.7
Reset anticipator	57.1
Gas leaks fixed	42.9
CO present and eliminated	42.9
Water leaks fixed	42.9
Oiled pump	28.6
Replaced gas valve	14.3
Cleaned heat exchanger	14.3
Revised h.e. flow pattern and adjusted fuel/air ratio	14.3
Repaired pump	14.3
Drained waterlogged expansion tank	14.3

This work was carried out on six forced circulation boilers and one gravity hot water boiler.