92.031B

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

LOW COST FURNACE EFFICIENCY IMPROVEMENTS 10,000 FURNACES LATER

Sun Power Consumer Association

Revised 6/06/89

Author:
John Proctor, P.E.

Reprinted by:
Proctor Engineering Group

Creators of CheckMe!®

LOW COST FURNACE EFFICIENCY PROGRAM - 10,000 FURNACES LATER

John Proctor and Bobbie Foster
Sun Power Consumer Association

(Revised 6/06/89)

INTRODUCTION

A low cost heating system efficiency improvement system was pioneered in the summer of 1982. That program showed a 12% heating savings and details of that program are described in the 1984 ACEEE paper, "Low Cost Furnace Efficiency Improvements" (Proctor, 1984). The results of that work showed promise, but left unanswered questions. First, can this technology and the administrative system necessary to accomplish it be transferred to other agencies from the organization that developed it? Second, which portions of the program were responsible for the majority of the savings? By 1984, Sun Power Consumer Association, with the help of the Colorado Office of Energy Conservation, had begun to answer those questions. By December of 1985 over 10,000 heating systems had been treated under the low cost program in Colorado. Over 10 agencies have been trained to deliver this program. The experience gained in those agencies on those furnaces shows that the success of this program depends on proper administration and a prioritized technical package.

We will look first at the administrative portion of the programs - BECAUSE THEY ARE THE LEAST UNDERSTOOD AND MOST IMPORTANT PART OF THE PROGRAMS. Without them the best technical package will result in only mediocre savings, administrative headaches, liability problems and possible unsafe conditions inside the clients homes. This administrative system is now used on three programs; the furnace program, the boiler program and the "House Nurse" program.

DISCUSSION

Administration

The administration of this program can be broken down into a few axioms they are:

AXIOM #1 - YOU CANNOT ASSUME THE TECHNICIANS, SUPERVISORS, INSPECTORS, AND HEATING CONTRACTORS ALREADY KNOW HOW TO DO WHAT YOU WANT THEM TO DO.

This means that adequate training is required to have the program save the energy that it potentially can. The reluctance of state administrators of weatherization programs to spend sufficient monies on training the individuals in the field results in insured lack of cost effective weatherization. This need has long been recognized but usually ignored. In the Modular Retrofit Experiment, Dutt (1982) noted " Greater energy savings should be possible with better building diagnostics, tighter control of house doctor performance, heating system modifications ... and more careful house doctor training." McAlister (1981) speaking of the training necessary to accomplish weatherization said "Training is the quality control of any job! There must be a regular schedule for training of individuals." When the delivering agencies evaluated the program the predominant request was for more training.

In order to accomplish adequate training the management system for these programs creates ongoing, formal and effective training-feedback to individuals at all levels of the organization. The training of the technicians is detailed in Proctor(1984). The ongoing feedback and work control system is shown below.

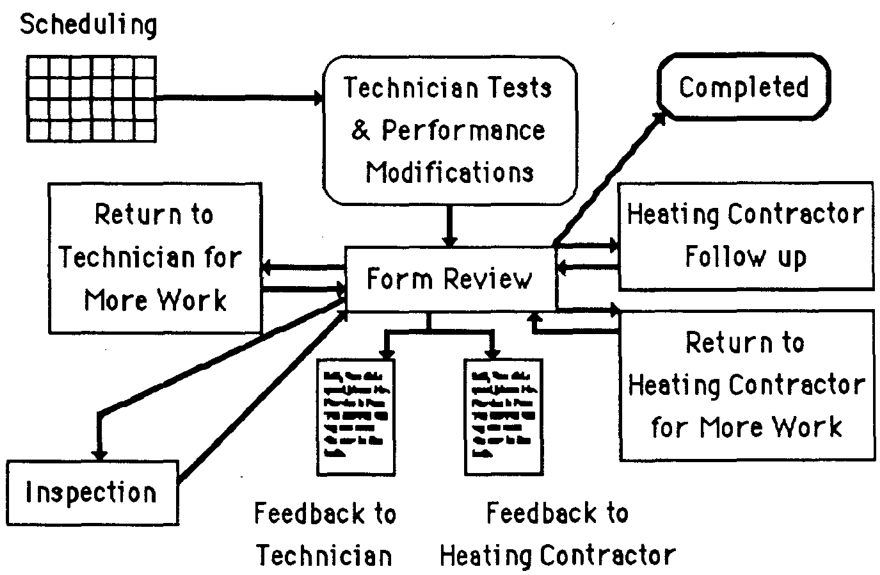

Figure 1. Feedback and work control system.

After the technician has completed their work, the form reviewer marks copies of the initial technician's test and modification form and returns these and any inspection feedback to the technician. Marked copies of the follow up sheets and inspection sheets are also returned to the person doing the follow up work.

The training of the supervisor/form review/inspector requires all the formal training of the technicians plus personalized feedback on at least five occasions over the next ten to fifteen weeks.

AXIOM #2 - "CLASSROOM OR LABORATORY" TRAINING CANNOT COMPARE WITH WORK IN THE PROGRAM COMBINED WITH RAPID AND ADEQUATE FEEDBACK.

AXIOM #3 - THE TECHNICIAN MUST BE WORKING AT A RATE SUFFICIENT TO LEARN FROM EACH UNIT. TIME DELAYS ENCOURAGE FORGETFULNESS NOT LEARNING.

The technicians must be doing at least 3 units per week following the initial training.

AXIOM #4 - YOU CANNOT ASSUME THAT THE HEATING CONTRACTOR OR THE TECHNICIAN DID WHAT THEY WERE TRAINED TO DO.

This requires that someone be trained to do a 100% review of the initial data on the heating system, the work done on the appliance and the final condition of the system. The 100% review is accomplished using paperwork designed to speedily and accurately communicate those items to the form reviewer. This process includes automatic and absolute rules on repairing dangerous situations.

AXIOM #5 - YOU CANNOT ASSUME THE TECHNICIAN OR THE HEATING CONTRACTOR FULLY UNDERSTOOD WHAT YOU SAID THE FIRST TIME YOU TRAINED THEM.

It is necessary therefore to give rapid (within one week) feedback via the form to the technician. In addition, inspection feedback should reach the technician or heating contractor within two weeks.

AXIOM #6 - YOU CANNOT ASSUME THAT EVERYONE IS OUT STRICTLY FOR THE GOOD OF THE CLIENT AND THE PROGRAM.

Follow up work on furnaces is done only as ordered by the individual who reviews all the forms. This is done with the assistance of the follow up flow chart . Since this greatly reduces unnecessary expenditure on repairs, it pays for the salary of the supervisor/ form reviewer/inspector.

AXIOM #7 - YOU CANNOT ASSUME THAT THE TECHNICIAN OR THE HEATING CONTRACTOR DID WHAT THEY WERE TOLD TO DO.

Inspection of the work is essential.

AXIOM #8 - YOU CANNOT ASSUME THE PROGRAM SUPERVISOR WILL BE RUNNING THE PROGRAM IN THE WAY THEY WERE TRAINED.

The funding source must have a trained monitor that periodically reviews both reports and actual work to insure the proper procedures are followed.

AXIOM #9 - PROGRAM SAVINGS EVALUATION AND FEEDBACK.

The best of us make mistakes and the only way to learn from them is to know they happened. Six months after the homes are treated by the program a utility use evaluation must be made. (The conclusions from this analysis can only be tentatively made until 1 year of data is available). This analysis will point out how the program is doing compared to our usually optimistic predictions. At that point corrections can be made in the administrative or technical portion of the program.

Heating System Programs

Existing heating system programs used as part of weatherization programs fall into three general categories:

1) Repair programs - repair discovered safety problems without much concentration on efficiency. They generally use existing heating contractors doing the work they most often do, that is repairing and replacing defective parts or whole units. These programs result in high costs and little or no efficiency gain.

2) Hardware programs - add various "energy saving" devices onto existing equipment. If the cost is relatively low compared to the savings (a <u>combination</u> of fuel price and the amount of efficiency improvement) then these programs can be cost effective (Such as the ASE oil retention head burner program).

3) Efficiency adjustments - adjust the existing equipment to the maximum efficiency attainable. In addition they may include elements of repair and hardware programs as they are selectively judged to be cost effective for an individual heating system. The low cost furnace efficiency program and the low cost boiler efficiency program fall into this category.

Liability

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 [our studies show that about 11% have that problem, (Proctor, 1984)], and IF the weatherization is successful, then the concentration of combustion products in the home is increased. Is not the agency's liability problem larger by not discovering the flue problem, thus leaving a life threatening situation which they have contributed to?

Program Savings

Table I. Furnace program savings studies.

Study	savings	N
Proctor, (1984)	12% (heat only)	28 units
Margolis, (1986)	8.4%	25
SERI-Frey, (1985) (data)	14.7% (heat only)	1
SERI-Subbaro et al.,(1986)	11.3% (heat only)	1
Claridge, (1985) (data only)		
Cat. 1	2.8%	45
Cat. 2	8.1%	16
Cat. 3	7.4%	9

When these studies are corrected to the same base (heat only energy use vs. heat and hot water use) they are in fairly strong agreement. The heat only (approx. 75% of the natural gas use) savings is around 11%.

Margolis - The Margolis study has a fair sample size and uses a control group which is from the same population (LIEAP recipients). It was able to obtain 24 months of data which eliminated the problem of units being eliminated because of insufficient pre treatment data. The study contains information about both hardware programs and efficiency adjustment programs. As in all these studies the problem of small sample size for the size of savings is a concern. This study is being updated with new data as it becomes available.

Solar Energy Research Institute - The building monitoring division of S.E.R.I. has undertaken three tasks which shed some light on the questions concerning what portions of the heating system efficiency program accomplish the savings found in previous studies.

In one building macrodynamic experiment (Subbaro et al., 1986), a new single family home was dynamically calibrated as a calorimeter. This allowed a determination of the total heating system efficiency. This system was (51.5 +/- 1.9) % efficient. The furnace was then put through the low cost efficiency program procedures and again tested. The result was a new efficiency of (58.1 +/- 1.9)%. This represents a heating season projected heating savings of (58.1 - 51.5) / 58.1 = 11.36%

In order to determine the cause of the savings on this single well instrumented home additional data was obtained on the furnace itself (Frey, 1985). To understand the importance of this study we must first examine the cycle of the typical furnace.

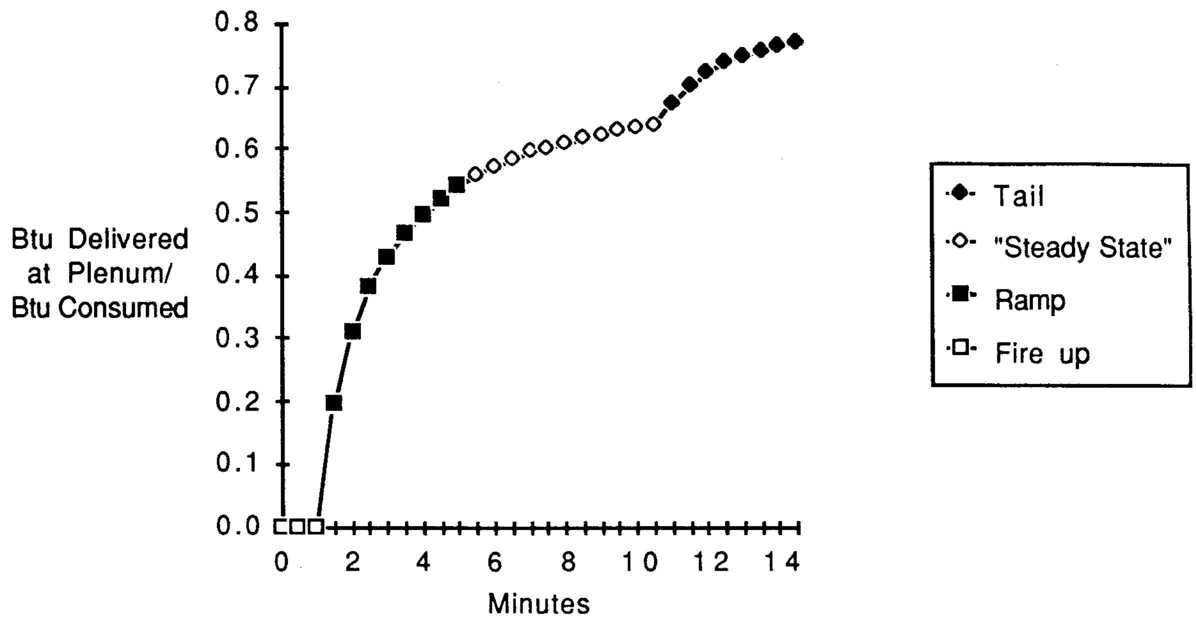

Figure 2. Phases of the furnace cycle. A normal furnace cycle has four phases.

Table II. Properties of the furnace phases.

Phase	Duration	Fuel	Blower	Comments
Fire up	1-3 min.	on	off	very little heat delivered
Ramp	2-5 min.	on	on	period of increasing eff.
"Steady State"	unlimited	on	on	highest heat delivery
Tail	1-8 min.	off	on	stored heat is delivered

The Frey data allow us to look closely at how the furnace actually performs and how individual portions of the process contribute to the total savings. Table III summarizes the information.

Table III. Frey study data.

Item	Original Condition	Modified
Natural Gas Input	1421 btu/min.	1421btu/min.
Start Up Duration	1 minute	1 minute
Start Up Btu Input	1421 btu	1421 btu
Ramp Input	2.5 min x 1421 btu = 3552 btu	3552 btu
Ramp Output	1899 btu	2620 btu
Heat Rise ("steady state")	Cycling on the limit switch	60°F
Delivery Temperature	Cycling between 146°F & 161°F	144°F
Btu Delivery (gas on "ss")	680 btu/min to 914 btu/min (average 797 btu/min)	1161 btu/min
Avg. Gas On Efficiency*	797/1421 = 56.1%	81.7%
Gas Off Heat Delivery	209 btu/burn minute	none
Modified "ss" Output	(680 + 914)/2 + 209 = 1006 /min	1161 btu
Modified "burn time" Eff.	70.8%	81.7%
Avg. Gas Off Temp.	153.5°F	144°F
Tail Heat Delivery	21.3 btu/°F drop	22.5 btu/°F
Temp Drop to 90°F	63.5°F	54°F
Total Tail Heat Delivery	1353 btu	1215 btu

* The efficiency change was primarily brought on by an increase in delivery air volume through a new higher speed blower motor. Not all of this gas on efficiency is translated into savings however. Since the furnace was "cycling on the limit" there was a period of time in the normal burn cycle when the gas was off but btu's were delivered. This gas off heat delivery amounted to 209 btu/ preceding burn minute.

Using this data we can calculate the overall efficiency for a number of different burn times. The results are summarized in Table IV for the furnace before and after modification.

Table IV. Overall efficiencies for various burn times.

Item	Original Condition	Modified
For a 1 minute start up, a 2.5 minute burn and equal fan off temperatures the furnace would produce:		
Total Input	3.5 x 1421 btu = 4973 btu	4973 btu
Avg. Gas Off Temp.	153.5°F	136.1°F
Tail Heat Delivery	21.3 btu/°F drop	22.5 btu/°F
Temp Drop to 90°F	63.5°F	46.1°F
Total Tail Heat Delivery	1353 btu	1037 btu
Total Output	1899 + 1353 = 3252 btu (Ramp Output + Tail Output)	2620 +1215 = 3835
Efficiency	65.4%	77.1%
For a 1 minute start up, a 5 minute burn and equal fan off temperatures the furnace would produce:		
Total Input	6 x 1421 btu = 8526 btu	8526 btu
Total Output	1006 x 2.5 + 1899 + 1353 = 5767	1161 x 2.5 + 2620 + 1215 = 6738
Efficiency	67.4%	79.0%
For a 1 minute start up, a 10 minute burn, and equal fan off temps the furnace would produce:		
Total Input	11 x 1421 btu = 15631 btu	15631 btu
Total Output	1006 x 7.5 +1899 + 1353= 10,797	1161 x 7.5 + 2620 +1215 =12,542
Efficiency	69.1%	80.2%

This detailed study suggests what some of the individual components of this program contribute to the overall savings. They are only suggestions since it is only one furnace.

Fire Up. In moderately cold weather the average furnace on time is 3 to 5 minutes (McGrew, 1979). There is therefore very little time spent in the "steady state" phase of the cycle. In fact, the ramp often leads directly into the tail with no "steady state" portion at all. There is no way known to the author which will improve the efficiency of the fire up phase. The best solution seems to be to reduce the duration of that phase (perhaps to zero - see research required).

Ramp. This phase seems to be significantly influenced by the air volume forced by the house air side of the heat exchanger. In this case, increasing air flow increased the delivery by 721 btu.

Steady State. Increased air flow also increases the efficiency of the "steady state" portion of the cycle. In this case it was increased by 10.9%.

Tail. The temperature drop and furnace mass determine the number of btu's delivered during this phase. In this rather typical furnace, every 10°F we are able to lower the fan off temperature we gain 220 btu. That is a 3% efficiency gain for a 5 minute burn.

Burn Time. Burn Time influences the final efficiency of the cycle. However, this influence diminishes to near zero when the tail is lengthened sufficiently.

The program originally adjusted the anticipator to increase the burn time. The risk is that the savings from increased burn time can easily be "eaten up" by increased average house temperature. Since proper adjustment of the fan off temperature substantially reduces the savings associated with burn time, the anticipator is now adjusted higher or lower than thermostat amps only when client complaints warrant such adjustment.

Claridge Data - This study started with over 800 furnaces. However it was very difficult to obtain an accurate representation of the furnaces that had significant work done on them. This was partially caused by the fact that only 14 months data was available from the utility and in many cases the request for data was too late to capture sufficient pre data. The "control group" was all residential gas customers of the utility, not just LIEAP recipients. The control group was analyzed only by heating season not necessarily encompassing the same dates as the experimental group. This is particularly important because of the way PRISM deals with nonlinear systems.

PRISM, NON-LINEAR SYSTEMS AND REAL WEATHER

The use of PRISM results in a very precise determination of three variables, reference temperature (Tref), base level consumption (A), and heating slope (B). For more discussion on these items see (Fels,1986). When the data is generated by a non-linear system, such as most heating systems, PRISM varies all three components in order to obtain the best straight line fit. Given three degrees of freedom it sacrifices accuracy in order to achieve fit. When used to analyze data on changes in non-linear systems, the results can be misleading. In order to investigate this phenomenon, we created five sets of theoretical performance curves for the house/heating system and fed the data to PRISM for analysis. These performance curves are generated for a balance point of 65°F.

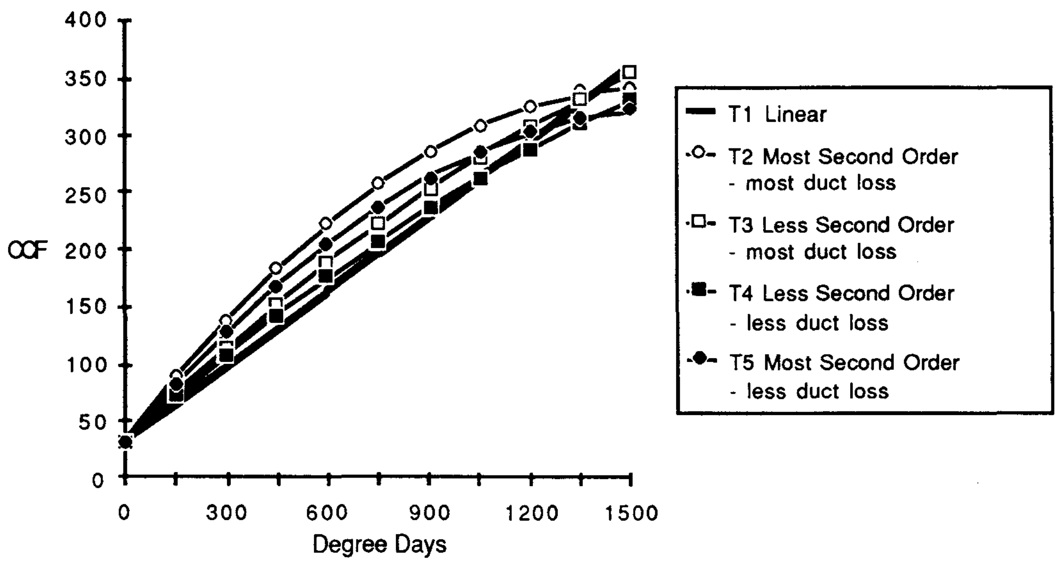

Figure 3. Theoretical linear and non-linear performance curves.

These five curves generated consumption data for the time periods 4/15/82 to 4/15/83 and 5/15/83 to 5/15/84. These were picked because they represented the predominant pre and post periods for the Claridge data. The 82/83 season had 6433 Degree Days (DD65). No individual data point had over 1060 DD65. The 83/84 season had 6678 DD65, with the highest data point with 1436 DD65. The 83/84 season was extremely different from normal. It included the "Christmas Blizzard of 83", which shut down the city of Denver. The extreme temperatures resulted in representatives of the utility company going on local radio and TV news programs telling people to turn UP their thermostats higher than normal. When the data points were fed to PRISM, the results were as shown in Table V.

Table V. Prism output for linear and non-linear systems.

ID	TIME	PERIOD	RXR	TREF	BASE LEVEL	SLOPE	NAC	C.I.
T1	4/15/82	4/15/83	0.9995	65	1.07	0.22	1819	
T2	4/15/82	4/15/83	0.9876	74	0.26	0.23	2270	
T3	4/15/82	4/15/83	0.9967	70	0.76	0.22	2002	
T4	4/15/82	4/15/83	0.997	69	0.86	0.21	1881	
T5	4/15/82	4/15/83	0.9894	73	0.37	0.22	2103	
T1	5/15/83	5/15/84	0.9991	65	1.03	0.22	1808	0.99373
T2	5/15/83	5/15/84	0.9777	78	0.09	0.21	2230	0.98251
T3	5/15/83	5/15/84	0.9965	70	0.89	0.21	1985	0.99131
T4	5/15/83	5/15/84	0.9845	67	1	0.20	1814	0.96438
T5	5/15/83	5/15/84	0.9819	73	0.06	0.19	2068	0.98359

The results show what PRISM does in order to accomplish a best fit straight line approximation. PRISM increased the reference temperature for second order consumption curves. The more arc the curve has the higher the reference temperature is increased. In addition for a particular set of weather data the higher the outlying DD reading, the more it increases Tref. PRISM also reduced the base level (A) for data with an arc and this phenomenon also increased as the weather mix included higher DD readings. A final note is that the non-linear systems produced a C.I. different from 1.0. Unity is the expected result for identical performance curves in two different years.

Conclusions concerning PRISM use

For linear systems, neither extremes in total degree days nor extreme weather conditions in an individual month should (in the absence of occupant behavior changes) reduce the reliability of conclusions drawn from PRISM. On the other hand, when the consumption is not linear it can be misleading the use C.I. as an indicator of savings. In this case identical efficiency curves (T4) resulted in a C.I. of .96 between the two seasons (the same two heating seasons that dominated the Claridge study). If we were to take the data at face value we would conclude that the system had been improved to accomplish a savings of 4%. For studies that deal with savings of small size, A CONTROL GROUP FROM THE SAME POPULATION AND THE SAME FUEL READING PERIODS IS ESSENTIAL!

With non-linear data the individual components of NAC (Tb, Base, and Slope) should not be interpreted as being meaningful in themselves. With these conclusions in hand we can examine the results of the Claridge study.

Claridge Study - We wondered if we could predict in advance which furnaces would show significant savings. Using the forms filled out by the technician, inspector, and follow up person the work done was categorized in one of the following categories

Table VI. Furnace savings prediction categories.

Indicator	Category 1	Category 2	Category 3
Delivery Temp	< 200°F	>200°F lowered to >150°F	>200°F lowered to < 150°F
Limit	not cycling	cycling due to low (<200°F) setting	cycling due to high temp (>200°F)
Fan On	<200°F	>200°F	fan broken
Ducts	connected	disconnected	Outside air to return
Anticipator	>.75 gas V amps	<.75 gas V amps	

We used the PRISM output from the Claridge study to analyze these furnaces. The first category had 19 units that normalized annual consumption (NAC) increased and 26 that the NAC decreased. Category 2 had 4 that increased and 12 that decreased. Category 3 was not significantly different from category 2. It had 2 units with increased NAC and 7 with a decrease. **As a result of this study we feel that we can screen furnaces in advance to determine which are the most likely to save energy and concentrate the program on them** (the most cost effective) as well as the furnaces with safety problems.

We found that the non-saving units in all categories had disproportionally more increased reference temperatures.

Table VII. Comparison of units that saved money vs those that didn't.

	Category 1		Categories 2 & 3	
Tref	saved $	lost $	saved $	lost $
higher	14 units	13 units	9 units	5 units
lower	12 units	6 units	10 units	1 unit

CONCLUSION

Forced air furnaces can be treated with a program that incorporates tight training and control. This administrative routine along with well selected technical options result in the minimum cost per btu saved.