RESIDENTIAL NATURAL GAS FURNACE PERFORMANCE STUDY

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ABSTRACT

The technology involved in the design and manufacture of residential gas furnaces has significantly changed in recent years. The many different models, brands and types of furnace units have prompted a study of the impact of these changes.

This paper discusses both the energy use changes realized when new furnace units have been installed, and the problems that owners who recently installed new furnaces have reported.

The study compares energy use changes in 72 households in the City of Madison that had new furnaces installed in the year 1983. The methodology used to analyze the energy savings normalizes the natural gas consumption so as to separate energy use data into weather related and non-weather related components.

This paper also discusses changes in the households' electric consumption related to the installation of the new furnace unit and compares changes in total energy usage with the difference in size of the new furnace to the old furnace.

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INTRODUCTION

In order to keep informed of recent changes in residential gas furnace technologies, the City of Madison Inspection Unit decided to study a sample of furnaces installed in the community. The study is designed to observe any problems that home owners have discovered which might be associated with the new furnace technology and to analyze the energy consumption performance of the furnaces.

Homeowners who installed new furnaces in 1983 were surveyed for their general energy use habits and for comments about the operation of their new furnace. Utility bill histories were the source of energy consumption data. Households were grouped by the amount of energy savings realized after the new furnace was installed and then analyzed to determine why some households saved more than others. Isolating the energy savings of one item, such as a new furnace, is difficult when other energy saving measures are being added and life style is changing. In cases where the change in energy use varied from the average, additional information was gathered from the home owners and incorporated into the study.

The study presents savings categories grouped by the magnitude of the savings, furnace efficiency ratings, sizing of the furnace, changes in electric use and total energy use. Along with the energy savings, problems with new furnaces are listed. The two main categories are mechanical breakdowns and exhaust venting troubles. Most problems were minor and handled under warranty. In general, most home owners indicated satisfaction with their new furnace.

Findings show that gas consumption declined by 21% with the new furnaces, which is a savings of 284 therms per year for the average household in this study. Changes in gas use ranged from an increase of 10% to a savings of 45%. The households with the largest savings, however, also added other energy conservation measures such as insulation or storm windows. On the other hand, those who had an increase in gas consumption usually increased their thermostat setting. Typically, furnaces with higher rated efficiencies saved more gas on a percentage basis than those with lower efficiencies.

Electric consumption increased after the new furnace was installed in the majority of cases. On the average, yearly electricity use increased 13%. Because some owners had central air conditioning installed along with the new furnace, electric consumption from October through May was studied. The average increase in electricity for these months was 12%. Some of this increase can be accounted for by the fact that the new furnaces were downsized from the old units causing the unit to run for longer periods of time to satisfy the household heating demand. Another source for additional electric use is a blower, usually associated with the exhaust venting, which is found in many of the newer furnaces.

In most cases, the new furnace heating capacity was smaller than the old furnace's capacity, on the average 30% smaller. Looking at the relationship between this downsizing of the furnace and energy consumption shows that gas savings increased with greater downsizing. On the average, large gas savers downsized their furnaces by 33% while the average group downsized 31% and the small and negative savers group downsized only 22%.

Considering both the increase in electric and the decrease in gas consumption, a new furnace saves energy. Participants in this study would average an 11% decrease in their total energy bills considering costs to be constant with gas at 63 cents per therm and electricity at 7 cents per kilowatt-hour. The amount saved depends on many factors, including: house size, fuel type used before the furnace was installed, energy use habits, other weatherization measures installed, and the building structure.

BACKGROUND

Several different types of furnaces were included in the performance study. There are those of conventional technology, pulse type models, models with a glycol heat exchange system, those with a heat recovery system in the exhaust and induced-draft type units. There are also differences in the techniques used to vent these units. The following description will briefly explain the different types of furnaces included in the study.

First there are the conventional models. These consist of the standard combustion chamber, heat exchanger, blower fan combination used to distribute heated air. The one difference common to most of the new models is that, instead of having a constant pilot light, electronic ignition systems have been added, decreasing the baseload gas consumption.

Next there are the pulse type models that have a pulsating combustion process. Gas and air enter and mix in the combustion chamber. A spark starts the cycle, igniting the gas and air mixture. Next, positive pressure closes flapper valves and forces exhaust gases down a tailpipe, creating a negative pressure in the chamber. This opens the flapper, drawing in more gas and air. At the same instant, part of the pressure pulse is reflected back from the tailpipe causing the new gas and air mixture to ignite. No spark is needed for that cycle. These pulses repeat 60 to 70 times per second.

Another model replaces the conventional heat exchanger with a heat transfer mechanism that contains both an electronic ignition and a combustion air blower. The heat transfer substance is a fluid mixture of glycol and water. The solution flows past a heating coil and is circulated back to the heat exchanger to be heated again until the heating demand has been satisfied.

The recuperative furnace models have a heat recovery system that removes heat from the hot exhaust gases and returns it to the system. Hot gases produced by combustion heat a primary heat exchanger. In a recuperative furnace the resulting gases, which in a conventional model furnace would be exhausted, are then passed over a secondary heat exchanger and more heat is recovered. The gases are then exhausted at much lower temperatures. Some condensation will occur and most models have a condensate drain tube leading from the furnace to a basement drain.

Finally, the induced-draft models have a special combustion air fan that reduces the amount of heated air normally lost up the chimney. Rapid transfer of heat through induced draft means that the flue gases do not reach the condensation point, eliminating the need for a condensate drain. The induced-draft models may be common vented with other gas burning appliances.

With lowered exhaust temperatures, there are new means of venting the furnaces. The units can be vented through a side wall in either a metal or a plastic pipe. Some models are still vented up the chimney, either in the existing stack or in a new metal liner. There will be more discussion of venting procedures in the Problems section of the report.

METHODOLOGY

Sources of Data

Heating permits issued in the City of Madison in the year 1983 served as the list of furnace installations to be investigated. The year 1983 was chosen because two years of consumption history were available after the new furnaces had been installed.

The background work before the first mailing included a check on the files of each building to eliminate buildings that had changed owners, had not used gas heat before installing a new furnace, or were not single family residences.

Data Collection

A survey of energy consumption habits along with a release form giving the City permission to obtain utility bill records was sent to each of 152 households. The response rate was very high, with 43% responding within the first ten days and 57% responding overall. A total of 86 surveys were returned, and the final sample was 72 buildings. Fourteen residences were removed from the study because information on the survey showed that they did not meet the criteria for a study sample.

After the list of buildings was compiled, the addresses and fuel consumption release forms signed by each property owner were sent to the local utility, Madison Gas and Electric Company (MG&E), along with a request for four year fuel consumption histories at each address. The energy consumption records were available on microfiche at MG&E.

Meanwhile, background information concerning the furnace efficiencies for different models was collected from local dealers and distributors. Many types of furnaces were included in the study. The Annual Fuel Utilization Efficiency (AFUE) ratings ranged from 73% to 95%, with the average being 87%.

Data Analysis

Natural gas consumption is normalized to separate nonweather- and weather-sensitive consumption, by statistically fitting the following linear model to the data.

$$\text{energy use} = \text{baseload} + \text{rate of fuel use per degree day} \times \text{number of degree days}$$

The model uses consumption information along with the degree day data to determine a baseload consumption, rate of fuel use per degree day for heating and a heating degree day reference temperature for each residence. Using these parameters, a value called the Normalized Annual Consumption (NAC) is calculated, which represents the household energy consumption for long range weather conditions, in effect eliminating fluctuations in the data from yearly weather variations. The NAC before the furnace was changed is compared to the NAC after the new furnace was installed to evaluate the degree of energy savings in household gas consumption. A decrease in the baseload value is noted in the energy consumption analysis. The baseload after the new furnace was installed dropped by an average of 30%. Most of this decrease can be accounted for by noting that in most cases an old furnace with a constant burn pilot light was replaced with a newer model containing an electronic ignition. For this reason, fuel use neglecting baseload use is not a good basis for comparison. The constant energy use by the pilot light is included in the household baseload in the before condition and then disappears after the new furnace is installed. For the purposes of this study, total household gas consumption will be the primary energy use indicator.

RESULTS AND DISCUSSION

Categorization of Households by Energy Savings

When the energy consumption analysis had been performed, home owners were categorized according to the amount of fuel that they saved on a percentage basis. The average household saved 21% of their gas consumption, a figure amounting to 284 therms per year. Figure 1. shows the actual amount of gas saved ranging from a negative 200 therms to over 1000 therms per year, while figure 2. shows the distribution of the percentage savings of natural gas ranging from a negative 10% savings to 45% savings.

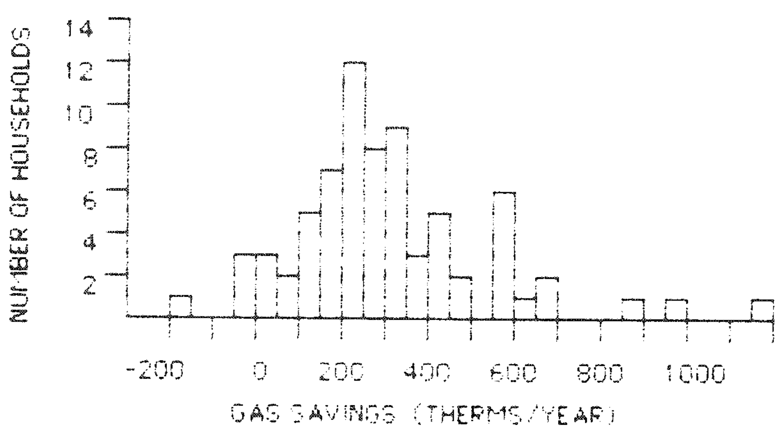

Figure 1. Natural gas saved (normalized data).

After plotting all of the home owners' individual energy consumption, four categories were chosen. They are the Large Savers, the Average Savers, the Small Savers and the Negative Savers. Large Savers were those that saved at least 32% of their gas consumption, Average Savers saved 12% to 32%, small savers saved up to 12%, and the negative savers consumed more natural gas with the new furnace than they did with the old one. Table I shows the average group characteristics such as gas and electricity consumption, furnace AFUE, floor area, and age.

TABLE I. Characteristics of households that replaced furnace units in 1983, by gas use consumption.

(a)	Large Savers	Average Savers	Small Savers	Negative Savers
Average gas savings (%)	39	22	7	-5
Previous gas use(therms/yr)	1440	1590	1930	1240
Gas Saved (therms)	575	280	85	-65
Previous Electric use(KWH)	9300	6800	6850	7300
Electric use increase (%)	11	14	12	13
Dollar Savings ($/yr)	350	140	40	-80
Change in Furnace Size (%)	-33	-31	-21	-23
New Furnace AFUE (%)	89	88	84	77
Floor Area (sq. ft)	1750	1600	1900	1250
House Age (years)	36	33	32	28
Number of Houses	12	46	8	6

(a) Large Savers saved > 32%; Average saved between 12% and 32%; Small savers saved up to 12%; Negative savers increased gas consumption.

These categories proved helpful later on in the analysis work in determining possible causes for fluctuations in the data. In order to interpret the wide variation in fuel consumption, another survey was done of all Large Savers, Small Savers and Negative Savers. Table II shows changes that were made at residences which caused them to save or use more energy than the average group. Those residences that did something to effect their energy consumption are identified on the savings distribution graph of figure 2.

Table II. Items affecting energy savings.

	Number of Households
Large Savers	
Added insulation	6
Added weather stripping or storm windows	2
Started setting back thermostat	2
Vacant through part of winter	1
Small and Negative Savers	
Increased thermostat setting	5

All of the Large Savers that were contacted had performed other energy conservation techniques along with the new furnace installation. Some of the large savers had simply reduced the thermostat settings, while others had performed a variety of structural weatherization improvements.

Most of the Small or Negative Savers had done something to cause their consumption to rise, counteracting the effects of the new furnace unit. These measures were primarily related to thermostat settings.

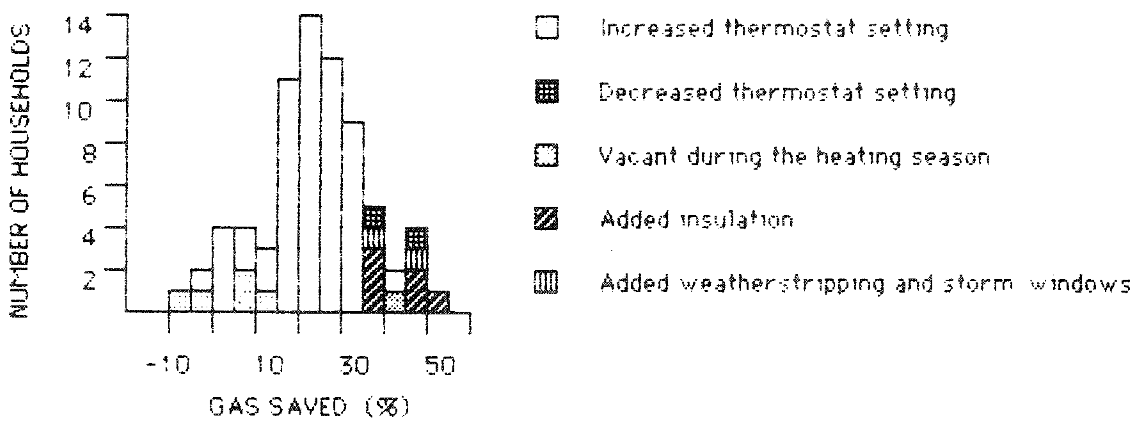

Figure 2. Distribution of other changes besides new furnace on gas use.

Looking at fuel savings without the above residences included, shows that the average fuel savings still remains at 22%. This average is reasonable since both large savers and negative savers were removed, offsetting each other's fuel use change.

Annual Fuel Utilization Efficiency Groupings

The AFUE ratings for the furnaces studied varied greatly. Figure 3 shows the furnace efficiency distribution of units studied. An analysis was performed to consider fuel consumption savings according to AFUE. Figure 4 shows the average change in gas consumption for each AFUE rating, varying from a 30 percent savings to a 12 percent increase.

The individual data shows performance by model, as each efficiency rating represents a single model in our study. The performance of each furnace varied by household. Again, in some cases there were other influences on the fuel consumption other than just the change in furnace unit.

To compare the new AFUEs with the amount of energy savings expected, both graphs should be examined. In the graph depicting the reduction in gas consumption verses the new furnace AFUE, each bar represents the average amount saved for all households having installed that unit. For example, the 31% savings shown for the units with an AFUE of 95% represents 11 installations, while the 21% savings shown for the 93% efficient unit represents only one installation. Notice that both installations where the gas consumption rose represent only one household each.

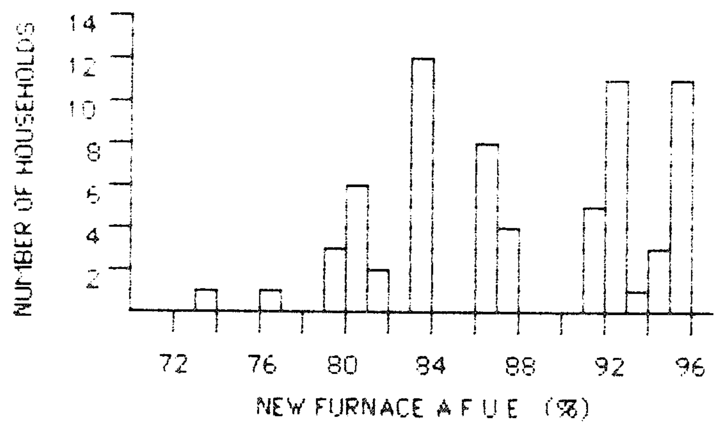

Figure 3. Furnace efficiency distribution.

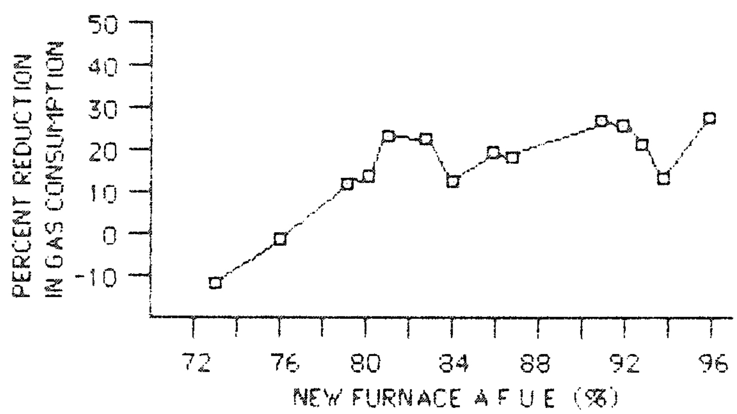

Figure 4. Reduction in gas consumption vs. new furnace AFUE.

Downsizing Categories

It became apparent from looking at all of the data available for each residence that the degree of difference in size between the old and the new furnaces was responsible for some of the differences in energy savings noticed in similar installations. In fact, when these numbers were correlated, it was shown that those houses where the heating plant size was decreased 30% or more saved more fuel, 21% and 26%, than the fuel savings, 16% and 17%, of those residences where the decrease in size for the new furnace was smaller. Table III illustrates the correlations.

TABLE III. The change in energy consumption correlated to the change in furnace size.

Decrease in Furnace Size (%)	>50	50-30	29-10	<10
Change in Electric Use (%)	+6	+13	+8	+10
Change in Gas Use (%)	-26	-21	-17	-16
Average AFUE (%)	90	88	85	83
Number of Houses	9	27	19	8
Furnace size before (BTUH input)		(Average 125,000)		
Furnace size after (BTUH input)		(Average 84,000)		

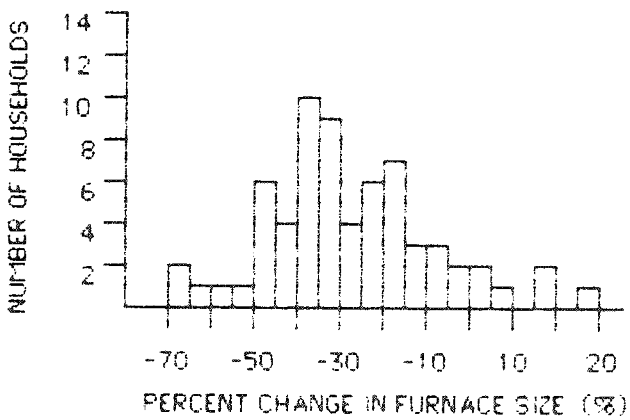

Figure 5. Change in furnace size.

Several home owners commented that they consider the house to be more evenly heated with the smaller unit, and that cold spots in the house have been eliminated. If the furnace is running for longer periods, then warm air is circulating for longer periods, possibly evening out temperature variations in the house. Other owners sensed that the temperature of the heated air coming out of the furnace ductwork was "cooler". This was never measured by any of the owners, however.

Electricity Consumption Increases

Changes in electric consumption were considered from a number of different viewpoints in order to characterize which installations would tend to consume more electricity. Findings show that electric consumption increases were scattered throughout all of the groups of savers. Refer to Table I.

Little or no correlation exists between electricity use increases and the magnitude of natural gas saved by any household. The electric consumption increase is attributed to the new furnace since the data shows that electric consumption is stable before and after the installation. The large change comes about when the furnace was replaced.

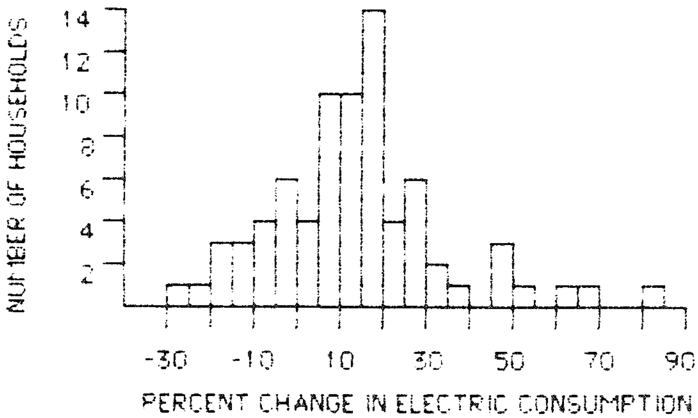

Figure 6. Electric consumption change (raw data for entire year).

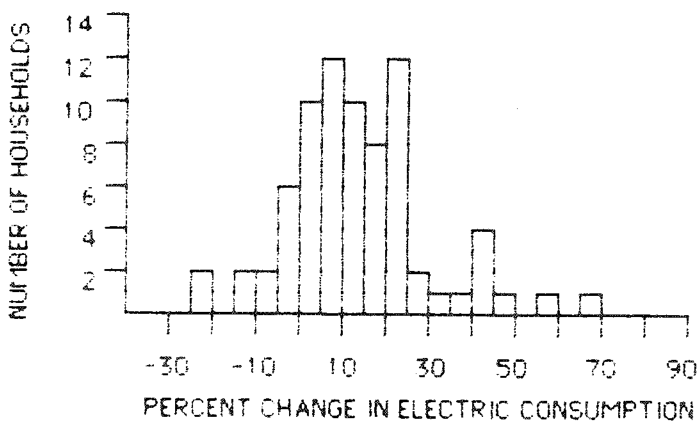

Figure 7. Electric consumption change (raw data for October through May).

Because some homes added central air conditioning with the new furnace, changes in electric consumption were considered for both the total year (figure 6) and for the heating season alone, October through May (figure 7). The results from both comparisons were similar (an 11% increase in use), which indicates that air conditioning is not the main reason for electric use increases.

Total Energy Use

Because electric consumption increased in most residences while the gas consumption dropped, the total energy use in each household was examined. The findings were positive in terms of energy savings.

Although electricity use increased, natural gas makes up a larger proportion of the total energy used in a household. When natural gas and electric consumption are combined together, by converting both to British Thermal Units (BTUs), the total energy use results. Figure 8 shows total energy use dropping in the composite group.

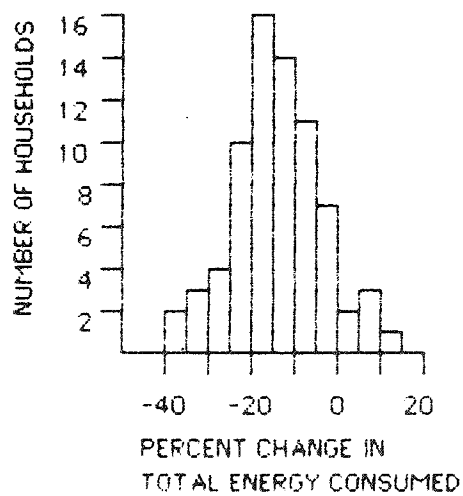

Figure 8. Change in total energy consumed (full year).

Using gas priced at $0.63 per therm and electricity at $0.07 per KWH, the average yearly utility bills for households in the study before and after the furnace installation are $1335 and $1191 respectively. This comparison yields a $144 or 11% annual savings. For an average electricity consumption of 6880 KWH, a 13% increase at 7¢ per KWH would cost $63. In terms of energy use, a new furnace would have to save at least 100 therms of natural gas per year in order to make up for the average increase in electricity use. These values will vary widely for individual residences depending on their current energy usage.

PROBLEMS

Home owners were asked on the survey form to describe any problems with their furnaces. Their responses fall into three categories: mechanical failure, exhaust venting problems, and comfort complaints. While 30% of those surveyed mentioned some problem, all but two of the households were very satisfied with their new furnace.

The majority of problems reported were mechanical failures such as the electronic ignition or controls failing, and were usually repaired under warranty.

Venting problems accounted for another third of the problems reported. The venting difficulties were usually a result of the much lower exhaust temperatures of the new furnace units. When vented through an existing chimney, there were reports that condensation occurred before the gases escaped, and drained back down through the stack. This problem was solved by either venting to the outside, or by installing a new, usually metal, stack in the existing chimney.

The other venting trouble mentioned was the formation of ice at the exterior side wall exhaust vent. In most cases, the vent cap was changed and the problem subsided. A variety of vent cap styles were used.

Two households reported cold wind blowing in through the side wall exhaust pipe effecting the controls which would shut down the furnace. One resident noticed a gas smell from this reverse flow in the vent pipe.

Table IV. Count of combustion gas venting methods.

Through the chimney	28
Through a side wall	
Plastic pipe	37
Metal pipe	14

The most common comfort complaint was noise. In the case of the pulse type furnace, a muffler device usually remedied any problem. All of the noise complaints, however, were not from the pulse type furnaces. Humidity was mentioned four times. In three instances, owners indicated that humidity levels increased after installing the new furnace. One resident, who experienced excessive condensation and even mold growth on the walls, installed an air-to-air heat exchanger to bring fresh, dry air into the house.

The following summarizes the twelve reported cases of mechanical problems from the new furnace installations:

1. The automatic controls for sequencing the heating cycle failed.

2. The heat exchanger leaked.

3. The recuperative coil leaked water.

4. The electronic ignition failed at three houses.

5. The small motor in the draft inducer fan failed.

6. A faulty valve was replaced under warranty.

7. Pipes vibrated.

8. In the first season the unit failed to start in extremely cold temperatures. An additional control solved the problem.

9. The blower fan stopped prematurely during heating, little heat reached the second floor, an occasional smell of gas was present, and there was a back draft in the vent on windy days. Controls were replaced.

The following describes reports of problems related to venting the furnaces:

1. The side wall vent leaks. Ice forms on the outside of the house and leaks into the basement when it melts.

2. Ice builds up under the plastic vent pipe.

3. The side wall vent pipe ices up in cold weather. The 90 degree angle vent cap was replaced with a 45 degree cap.

4. Moisture through a side wall vent iced shrubbery and caused paint on the house to peel. Venting was rerouted up the chimney stack.

5. The bottom of the metal side wall vent pipe has begun to corrode.

6. Removing the furnace exhaust from the chimney, caused the water heater exhaust to freeze in a 2-story house. A metal sleeve was placed in the chimney to solve the problem.

7. Cold air blew in through the side wall vent, causing a smell of gas.

There seems to be no definitive answer to the results of having reduced temperature exhaust gases. Complications have developed in both cases where the venting is done through the side walls and where the venting remains up the chimney.

CONCLUSIONS

The most important findings of this study are the actual energy savings of 21% on the household gas consumption realized when residents installed a new, usually smaller and more efficient, furnace. There is a resulting increase in electric consumption caused by replacing the old furnace with one of a smaller rating. This 13% increase in electric consumption, however, is more than offset by the decrease in gas use since natural gas consumption is the largest part of the total energy consumed.

The percentages resulting from the energy analysis cannot separate out other energy use changes that may have occurred in each residence. However, there appears to be a mix of households where the energy consumption increased as well as those where the energy use decreased. The average values then are what might be expected when installing a new furnace system.

Three separate categories of changes in energy use habits after the new unit was installed are apparent: those households that did not change their energy use habits, those that employed other energy conservation techniques than just the new furnace installation and those that decided that because the new furnace used less gas to operate, they could increase their comfort level and adjust the thermostat to produce a warmer house.

The results of the energy analysis performed on each household should show the magnitude of savings expected when new furnaces are installed under varying conditions. An owner planning on a new furnace can compare average savings realized when other energy conservation techniques are employed as well as when the energy consumption of the household increases because of higher thermostat temperatures.

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