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The Development of a Field Furnace Test: A More Accurate Prediction of Seasonal Efficiency

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THE DEVELOPMENT OF A FIELD FURNACE EFFICIENCY TEST: A MORE ACCURATE PREDICTION OF SEASONAL EFFICIENCY

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Introduction

Forced Air Signature Testing, or FAST, is a recently refined furnace efficiency test procedure with important implications for demand side management and weatherization. FAST accurately determines actual installed furnace efficiency, potential furnace retrofit or replacement furnace savings, and actual retrofit or replacement savings. It can be used to determine what portion of a package of energy savings measures is attributable to furnace retrofits. Using examples of actual applications, this paper describes the development, testing details, and benefits of FAST. Test validation is also discussed.

The development of this test allows substantial improvement of any audit, savings or other calculation that involves furnace efficiency. Decisions between furnace replacement and repair can now be made based on measured results rather than guesswork. The predictive ability of FAST is enhanced substantially by the use of tests at three different cycle lengths.

What is Furnace Efficiency and Why is it Important?

Decisions on furnace replacement, furnace retrofit, and in some cases the potential savings due to shell measures, are based on the installed efficiency of the furnace. In the absence of an adequate field furnace efficiency test, utilities and weatherization agencies have used "educated guesses." The result is inaccurate savings predictions and compromised program decisions.

The efficiency of a furnace is the Btu's of heat delivered by the furnace divided by the input Btu's to the furnace (Equation #1). The efficiency would be 100% if there were no energy losses so that all the energy input was delivered as heat (Equation #2). Table 1 lists energy loss from the furnace.

Equation #1: $\textbf{Efficiency} = \dfrac{\textbf{Output}}{\textbf{Input}}$ Equation #2: $\textbf{Output} = \textbf{Input} - \textbf{Losses}$

Table 1: Furnace Losses

Loss	Description
Flue loss (on cycle)	Energy lost out the exhaust vent carrying the combustion products from the building
Flue loss (off cycle)	Energy left in the heat exchanger at the end of the cycle and lost out the exhaust vent while the furnace is off
Jacket loss	Energy loss from the furnace to the furnace room
Pilot loss	Energy used in maintaining a standing pilot
Infiltration loss	Infiltration energy loss of the building due to the exhaust vent
Distribution loss	Energy loss to unheated space by the distribution system, infiltration effects of duct leaks and imbalance effects

There are two fundamentally different approaches to measuring the efficiency of a furnace. The most common method is to measure or estimate the loss, convert it to a percentage, and subtract the result from 100%. The most common measure is the "steady-state" efficiency, which merely reports the on-cycle stack loss after a long furnace run (20 minutes is needed). The "steady-state" efficiency therefore represents an idealized picture of the operation of the furnace at one particular point in time.

The second approach to determining the efficiency is to measure the output of the furnace over complete cycles or longer time periods and divide that quantity by the energy input over the same period. This procedure obviously gives a more complete picture of furnace efficiency. When the efficiency is measured in this manner for a whole cycle the result is called "cycle efficiency."

FAST determines the efficiency of furnaces in the second, more complete manner. The energy output of the furnace to the distribution system is measured from the beginning of the cycle. The input is measured at the same time. At any point in the cycle, FAST defines the cumulative efficiency as the total energy output of the furnace divided by the total energy input up to that point in the cycle. A plot of cumulative efficiency vs. time is shown in Figure 1.

Problems with Testing Steady-state Efficiency to Derive Furnace Efficiency

Because of the limited nature of the steady-state efficiency test, inaccurate conclusions about seasonal efficiency have been drawn. An example of the use of steady-state efficiency to estimate seasonal furnace efficiency is the Residential Conservation Service program audit. The *Residential Energy Audit Manual*, prepared by the U.S. Department of Energy, provides guidelines for the determination of seasonal efficiency based on the measured steady-state efficiency and the type of furnace. The furnaces are categorized according to whether they have a vent damper and/or an intermittent ignition device.

Once the steady-state efficiency (SSE) has been measured, a table is used to look up the estimated seasonal efficiency correlated with the SSE (Ref. 11, p. 347). This methodology is used extensively throughout the United States. However, it has serious limitations since it does not include the most critical parameters in seasonal efficiency beyond steady-state efficiency: cycle length and fan-off temperature. Both of these variables can have a profound effect on seasonal efficiency and must be taken into consideration. The *Residential Energy Audit Manual* method excludes them.

In order to illustrate the importance of considering cycle length and fan-off temperature in calculating seasonal efficiency, the Residential Energy Audit model has been applied to five furnaces tested in a 1990 PG&E study conducted by Proctor Engineering Group (ref. 9). The estimates derived using the audit guidelines differ markedly from the measured efficiency figures from FAST tests conducted on these units. The comparison appears in Table 2.

Comparing SSE to FAST is like comparing a snapshot to a motion picture. SSE gives an accurate picture for a single frame or moment in time, while FAST results in multiple frames over several complete cycles and therefore provides a more comprehensive picture of furnace efficiency under a variety of conditions. Since FAST collects data for a variety of conditions, it can model the actual efficiency over the entire heating season or for any period of interest.

Table 2: Audit Estimates vs. Actual Seasonal Efficiency

1990 Fresno Study	*Residential Energy Audit Manual* Estimated Efficiency(%)	Initial Efficiency (%) Measured with FAST	Efficiency After Work (%) Measured with FAST
#1	60	46.7	N/A
#2	72	66.6	78.1
#4	58	76.5	77.1
#5	57	61.7	61.0
#14	68	42.0	71.1

History and Evolution of FAST

Forced Air Signature Testing (FAST) was developed in response to the need for a more inclusive and accurate measure of on-site furnace efficiency. FAST has been used successfully in several projects and has evolved with each use:

- Jay McGrew (Ref. 5)
- The Solar Energy Research Institute (Refs. 3 and 9)
- Sun Power Accelerated Monitoring program (Ref. 2)
- SERI study of furnace efficiency modifications (Ref. 4)
- Wisconsin Gas Co. furnace efficiency improvement pilot program (Ref. 12)
- PG&E Heat Pump Efficiency and Weatherization Project (Ref. 8)
- PG&E Appliance Doctor Pilot Project (Ref. 10)

FAST was initially used to determine furnace efficiency for 10-minute cycles. It developed into a tool to measure pre- and post-modification efficiency and savings. Cycle length is a critical parameter in measuring the efficiency of installed furnaces. In order to calculate performance at other cycle lengths (e.g., 4 minutes, 12 minutes, etc.), it was necessary to make assumptions based on the 10-minute results.

The Development of Defining Equations: A Major Breakthrough

In SERI's 1989 test of furnace efficiency modifications, Short-Term Energy Monitoring (STEM) test results obtained pre- and post-modification overall efficiency. Sun Power, the contract administrator for SERI's 1989 test, added FAST to the series of tests being conducted in the project. For the first time, FAST was modified to measure:

- different cycle lengths (5-,10-, and 20-minute cycles)
- different parameters for each cycle length (e.g., temperature rise, fan-off temperature)
- temperature rise at the beginning of the cycle

The importance of replicating initial test conditions, particularly temperature rise at the beginning of the cycle, was discovered at this time. The SERI project found that this variable must be controlled so that it is constant for each test. If initial test conditions are successfully controlled, FAST calculations have proven to be extremely repeatable.

At this point, the author developed a method of determining defining equations for each furnace. Assisted by a three-dimensional computer graphics program, the investigator derived linear equations which described furnace performance under a wide range of conditions. This is described further in the Results section.

SUBSEQUENT USE OF DEFINING EQUATIONS

After defining equations were developed, FAST was used for the first time on commercial roof-top furnaces in Wisconsin, allowing immediate analysis of the program's effectiveness in obtaining the desired savings. It was later used to test the on-site efficiency of heat pumps for PG&E (Proctor et al.). The most recent application of FAST was the 1990 PG&E Appliance Doctor Pilot Project, in which furnaces and air conditioners at five homes in Fresno, California were tested.

What is FAST?

The instantaneous output of each furnace generates a very repeatable pattern which forms a "signature" of that furnace. When adequately characterized with respect to the operating parameters of cycle-on and off time, the furnace signature determines the efficiency of the unit for the entire heating season. FAST provides this characterization by measuring the output over entire cycles.

Measuring the energy from the furnace into the house airstream (output) for an entire cycle, then dividing it by the amount of gas burned for that cycle, gives the efficiency for that cycle. In order to calculate the output, airflow in CFM and temperature rise are measured. Input is easily measured by clocking the gas meter while the furnace is operating.

The test is conducted sequentially for 5-, 10-, and 20-minute cycles while varying individual furnace operating parameters to gauge the effect of those particular parameters on performance. Fan-off temperature and cycle length are the two most critical parameters. The effect of airflow rate across the house air side of the heat exchanger has been tested also and is of lesser importance.

Essential Elements of FAST

- Tight control of testing procedures
- Measurement of furnace airflow, temperature rise, and input
- Calculation of cumulative furnace efficiency
- Prediction of furnace performance under various conditions (derivation of the defining equations for each furnace)

Testing Details

Measurement of Airflow

The airflow through furnaces can be tested in many ways. Carrier's "Air Properties and Measurement" (1978) provides a summary of methods and more detail on the three methods that have been employed in furnace signature testing. Common techniques use a hot wire anemometer or a heat source such as an electric resistance heater.

The first method, used by McGrew, is to use a hot wire anemometer by traversing a probe across the airstream. The probe contains a wire that is heated by an electric circuit. When the airflow increases, the current through the wire increases. The change in current is used to measure the airflow.

Another technique involves the installation of an electric resistance heater in the delivery plenum to input a known amount of energy into the airstream. The temperature rise method detailed below is then used to measure the total airflow through the furnace. This method was used in the 1985 SERI study and, using existing electric resistance back-up heaters, in the 1990 PG&E heat pump study.

The Temperature Rise Method. Measuring the airflow by the temperature rise method involves supplying a known amount of energy to the airstream and measuring the resulting difference in temperature between the supply plenum and the return plenum. This gives the temperature rise. The primary method of supplying the known amount of energy in the FAST test now uses the furnace. In the furnace signature test, steady-state efficiency and temperature rise (SSE and ΔT_{20}) are measured after 20 minutes of continuous operation.

The airflow, in cubic feet per minute (CFM), is calculated as follows:

$$\text{Equation \#3:}\quad \mathbf{CFM} = \frac{\mathbf{.926\ X\ Energy\ into\ Airstream\ (Btu/Hr.)}}{\mathbf{\Delta T_{20}\ (^\circ F)}}$$

Where:

Energy into Airstream = Input Btu/hr X SSE
ΔT_{20} (°F) = Steady-state Temperature Rise 20 minutes into the cycle

The conversion factor is derived as follows:

A = 0.018 Btu/°F ft^3
B = 60 minutes/hour

$$\frac{1}{A \times B} = .926$$

Measurement of Steady-State Efficiency. Input to the airstream is determined by running the furnace until the mass of the furnace has reached a nearly constant temperature. In the signature test procedure, this measurement is always conducted at 20 minutes from the gas-on event. For the entire 20-minute period, the gas must continue to burn, the delivery blower continue to run, and the burn must be complete (<100 ppm CO in the flue gas). At the end of this period the combustion efficiency is measured using standard SSE test methodology. This determines steady-state efficiency as a percentage of the furnace input rate.

Measurement of Temperature Rise. A thermocouple is used to measure the mixed supply air temperature and the mixed return air temperature. In FAST the temperature rise is measured every 15 seconds. The steady-state reading is an average of the 15-second temperature rises in the last 2 minutes of the 20-minute cycle. A thermocouple grid is placed in the delivery system to measure the mixed air temperature leaving the furnace. This grid is placed so that it is not influenced by radiant effects from the heat exchanger. The return temperature is also measured with a thermocouple placed to sense mixed air temperature. When conditions such as separate returns are encountered, multiple thermocouples are used to average the temperatures.

Calculating Furnace Output and Cumulative Efficiency

Furnace output in BTU per hour is based on temperature rise and airflow measurements, as expressed by:

$$\text{Equation \#4:}\quad \mathbf{Output = CFM\ \ X\ 1.08\ X\ \Delta T}$$

The furnace output for each 15-second segment is calculated by the formula:

$$\text{Equation \#5: When the blower is on, } \mathbf{Output} = \frac{\mathbf{\Delta T_{avg}\ X\ 1.08\ X\ CFM}}{\mathbf{240}}$$

$$\text{Equation \#6: When the blower is off,}\qquad \mathbf{Output\ =\ 0}$$

<u>Where</u>

ΔT_{avg}	=	average temp. rise between delivery and return temperatures for previous 15 seconds
1.08	=	A x B the reciprocal of .926 used in Equation #3
240	=	15-second periods in one hour.

The furnace input for each 15-second segment is calculated by the formula:

Equation #7: When the gas is on,

$$\textbf{Input} = \frac{\textbf{elapsed time (sec.) X Input (Btu/hr)}}{\textbf{3600 sec. per hr.}}$$

Equation #8: When the gas is off, $\textbf{Input} = 0$

The cumulative efficiency at any time in the cycle is calculated by the formula:

Equation #9: $$\textbf{Cumulative Efficiency at time } t_n = \frac{\sum_0^n \textbf{Output}}{\sum_0^n \textbf{Input}}$$

which is the sum of all the 15-second outputs from the time the gas comes on until the time t_n divided by the sum of all the inputs until time t_n.

The cumulative efficiency for one house in the Fresno study is shown in Figure 1.

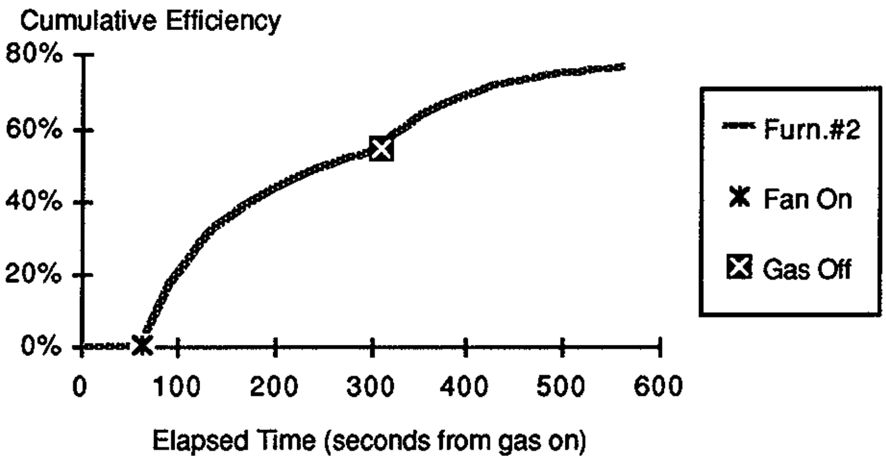

Figure 1. Furnace Signature (5-Minute Cycle) - Furnace #2

Derivation of Defining Equations

The cycling efficiency (cumulative efficiency at fan-off) is essentially a linear function of the fan-off temperature for each cycle length. Figure 2 gives the cycling efficiency of a furnace from the Fresno study after repairs were conducted .

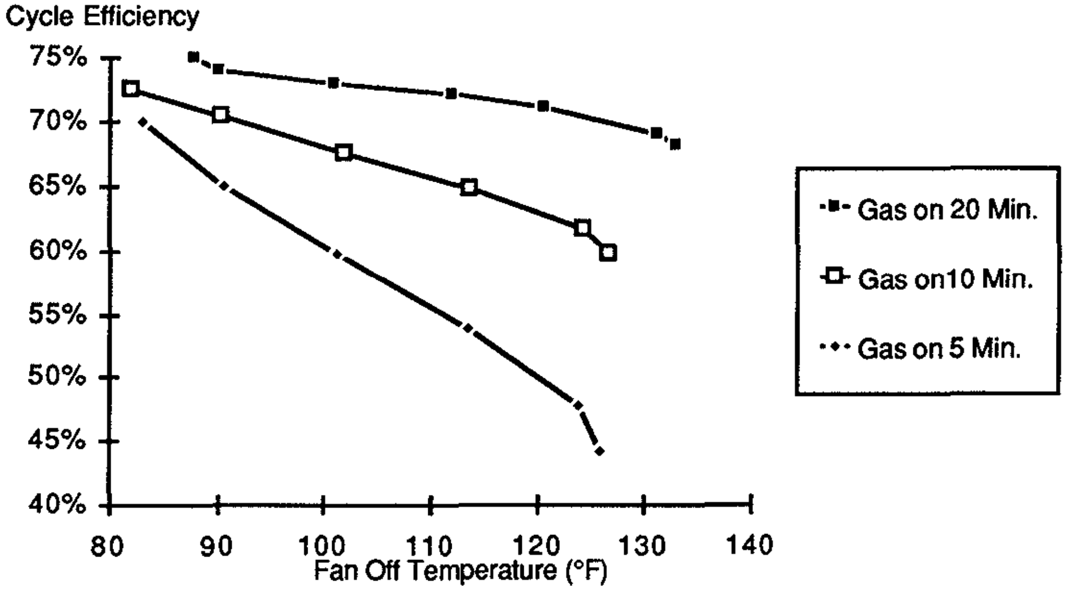

Figure 2. Fan Off and Cycle Length Effect on Efficiency - Furnace #5

These series of curves can be represented by the general equation:

$$\text{Equation \#10:} \quad \textbf{Cycling Eff.} = \alpha + \beta \times \frac{(T_{off} - \gamma)}{t_{cycle}}$$

Where

α	=	the intercept of the regression, this approaches the Steady-state efficiency
β	=	slope (a constant), efficiency increase due to changes in fan-off temp. and gas cycle length
T_{off}	=	temperature of the delivery air when the fan turns off (°F)
γ	=	hinge point, this approaches the return air temperature at the time of the test
t_{cycle}	=	cycle time from gas-on to gas off

Defining equations are derived for each furnace under each test condition (pre-/post-modification) by a two-step process. The cumulative efficiency for a number of fan-off temperatures is extracted from the monitored data. These data points are used in an iterative regression analysis which determines α, β, and γ. The regressions are performed to obtain the best R^2 for these data points. Defining equations for the five furnaces tested in the Fresno study are reported in the Results section of this paper.

Test Control

Experience dictates that the testing procedures be precise in order to isolate the effect of the tested modification from variations in testing. This is best accomplished by utilizing a data acquisition system or equivalent to:

1. Record delivery and return temperature data at least every 15 seconds.
2. Monitor and record gas valve and fan condition (on/off).
3. Abort the test if critical test parameters are exceeded (initial delivery/return temperature differential, gas valve cycling on and off).
4. Remind the technician, via a beep and screen prompt, to measure the steady-state efficiency at the proper time.
5. Using prompted inputs, record the test conditions and technician measured results in one file for later analysis.

The difference between supply and return temperature at the beginning of the cycle is a critical aspect of the initial conditions for the test. If all the usable energy is gone from the heat exchanger at the beginning of the test cycle, there will be almost no difference between supply and return temperatures. The initial conditions must be the same for each cycle tested in order to obtain valid results. If the gas valve is cycling off and on, steady-state will never occur and steady-state efficiency cannot be determined.

Calculation of In-Place Efficiency and Savings

In-place efficiency can be calculated by substituting the actual fan-off temperature and cycle time into the defining equation for that furnace. The actual cycle time for furnaces was measured by Sun Power (Ref. 2) and found to vary from furnace to furnace. The measurement should be taken in the field. The average gas-on length varied from over 20 minutes to less than 2 minutes and averaged 4.5 minutes.

The savings is estimated by:

Equation #11: $$\text{Savings} = \frac{(\text{Cycling Eff. post} - \text{Cycling Eff. pre})}{\text{Cycling Eff. post}}$$

This analysis includes the following assumptions:

(1) The delivery temperature changes linearly between each 15-second recording period. This is approximately true for the period of interest (fan-on to fan-off).

(2) There is no heat delivered while the fan is off. This is only approximately true; there is some airflow past the heat exchanger during the period as the heated air rises. It is a particularly good assumption for roof-top furnaces since the heated air cannot rise away from the furnace. Early tests (Ref. 5) showed the actual fan-off flow rate slowly rising to about 15% of the fan-on flow.

(3) When the fan comes on the mass flow rate of the air is constant and at its steady-state value. This assumption also was shown by McGrew to be very close to correct.

(4) At 20 minutes all the energy supplied to the furnace is either lost up the stack or enters the delivery system as heated air. In fact a small amount of the energy is dissipated in jacket losses.

(5) The seasonal efficiency of the furnace (without the duct losses) is the same as the cycling cumulative efficiency at the average cycle length. This assumption is nearly true because the length of the gas-on cycle does not vary substantially except in very cold weather (Ref. 2)

These assumptions are basically true. When they are applied to tests of sufficient length the errors are insignificant. For very short cycles, however, they do become significant. For this reason the shortest test period used in FAST is 5 minutes.

The final assumption is that all the energy remaining stored in the mass of the furnace at the time the fan goes off is lost up the stack before the next cycle begins. This is only strictly true for relatively warm weather when the time between cycles is long. Two FAST tests of this parameter have been completed. Additional testing is necessary to fully characterize this effect.

The described efficiency calculation is based on the gas input. This excludes the electrical energy to run the fan or other parasitic energy (induced draft blower, etc.). Basing the calculation on the total energy use, including fan energy, reduces the efficiency for the entire cycle. It also limits the effective fan run time at the end of the cycle. Neither of these changes has a significant effect on conclusions about fan-off timing, since the run time at the end is actually determined by comfort considerations and the fan input is small compared to the gas input. Fan input is optionally included in the analysis.

Results Summary

Testing furnace cycling efficiency was limited to tests at a single fixed cycle length before the developments of 1989. By testing at a single cycle length, the true efficiency at other cycle lengths was left to mathematical modeling. When the protocols were extended to include testing at 5, 10, and 20 minutes it became possible for FAST to accurately determine the efficiency for a wide range of cycle lengths. This change also improved the predictive ability of the testing by basing conclusions on multiple as opposed to single tests. Multiple testing also created an internal check of the validity of each run.

Cycle length was not the only parameter that could be varied. In 1989, investigation of the parameters of air flow, fan-off temperature, fan-on temperature, and off cycle length were begun. The result was a wide variety of data that begged for analysis.

Utilizing new computer programs that project four different variables into a time/space plot allowed the investigator to visualize the potential relationships between these diverse variables. An example is the relationship between the cycling efficiency, air flow past the heat exchanger (measured by temperature rise), fan-off temperature, and cycle-on time. When these four variables were originally projected, they appeared as a series of three pronged forks floating in space. By deriving new variables that captured the interaction between these measured quantities it was possible to change the rather confusing picture into a simple plane that described the efficiency based on the three independent variables. The result for one of the furnaces is shown in Figure 3.

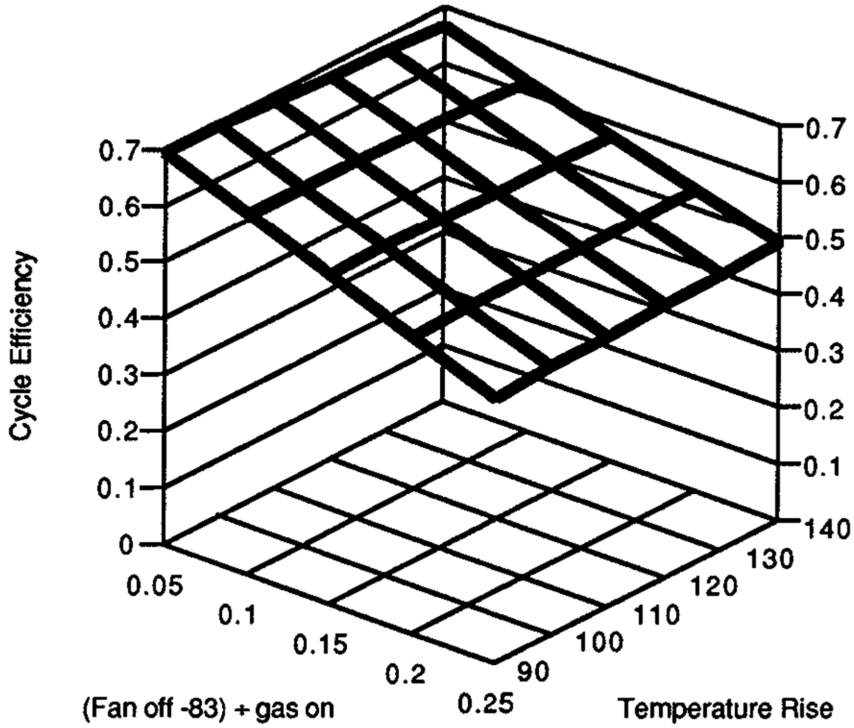

Figure 3. Relationship Between Cycling Efficiency, Fan-Off Temperature, Gas-On Time, and Temperature Rise

The defining equations for four of the furnaces in the 1989 study are:

89-01: **Cycling Eff.** $= .830 - .00084 \text{ X } \Delta T_5 - 1.631 \text{ X } \frac{(T_{off} - 83)}{t_{cycle}} + .00531 \text{ X } \Delta T_5 \text{X} \frac{(T_{off} - 83)}{t_{cycle}}$

89-02: **Cycling Eff.**$= .8783 - .001103 \text{ X } \Delta T_5 - 2.832 \text{ X } \frac{(T_{off} - 90)}{t_{cycle}} + .00992 \text{ X } \Delta T_5 \text{X} \frac{(T_{off} - 90)}{t_{cycle}}$

89-03: **Cycling Eff.**$= .7458 - .000058 \text{ X } \Delta T_5 - .978 \text{ X} \frac{(T_{off} - \gamma)}{t_{cycle}} + .0000265 \text{ X } \Delta T_5 \text{X} \frac{(T_{off} - \gamma)}{t_{cycle}}$

$\gamma = 148 - .5 \text{ X } \Delta T_5$

89-04: **Cycling Eff.**$= .7325 - .000278 \text{ X } \Delta T_5 - 2.195 \text{ X } \frac{(T_{off} - 108)}{t_{cycle}} + .01195 \text{ X } \Delta T_5 \text{X} \frac{(T_{off} - 108)}{t_{cycle}}$

Table 3 shows the defining equations for the five furnaces tested in the Fresno study before and after efficiency repairs were conducted.

Table 3. Defining Equations for Furnace Cycling Efficiency			
	Cycling Eff. = $\alpha + \beta \times \frac{(T_{off} - \gamma)}{t_{cycle}}$		
Identification	α	β	γ
Furnace #90-01 pre-	.7573	-1.551	76
Furnace #90-02 pre-	.8089	-1.869	87
Furnace #90-02 post-	.8061	-2.477	92
Furnace #90-04 pre-	.7936	-2.131	80
Furnace #90-04 post-	.7711	-2.816	96
Furnace #90-05 pre-	.7729	-1.115	62
Furnace #90-05 post-	.7745	-1.760	69
Furnace #90-14 pre-	.6299	-3.145	97
Furnace #90-14 post-	.7574	-2.313	94

Uses and Benefits of FAST

FAST accurately determines the actual cycling efficiency of forced air heating systems. This allows program managers and evaluators to:

- predict how furnace replacement and/or modification will affect efficiency
- improve the measurement of the results of furnace replacement or modification
- make predictions and know the results within hours
- make accurate long-term savings predictions
- determine how individual parameters affect a furnace or a group of furnaces to compare actual vs. potential savings and predict overall long-term savings.

FAST not only determines the savings of retrofits and adjustments to the heating system within hours of the modifications; it also gives an investigator the opportunity to differentiate the results of heating system modifications from changes in the building shell and delivery system.

FAST is an important management and quality assurance tool that can be used to identify program deficiencies and implement the necessary changes within weeks instead of months or even years as was often the case before the advent of FAST. FAST can determine the effects of easily measured parameters on the efficiency of the appliance. By specifying a few simple pieces of information from the field, program managers can determine the potential for savings that exists for every furnace and what portion of that potential will be realized from the work performed on that unit. The manager can therefore determine whether the program is going to reach its DSM/savings goal or whether it will fall short, requiring revision or cancellation. Such program decisions can now be made within days rather than waiting for an evaluation one year later. This data can also be used to analyze the performance of different agencies, contractors, and personnel charged with delivering furnace efficiency programs.

Test Repeatability and Accuracy

The reliability of FAST has been confirmed in the various studies discussed in this paper. This validation is broken into three areas: determination of repeatability, agreement with other short-term tests, and agreement with long-term statistical methods.

Each FAST series consists of repeated testing of the same unit running under nearly identical conditions for the first five minutes of the test. The calculated cumulative efficiency of the unit at 300 seconds for the 5-, 10-, and 20-minute tests measures the repeatability of the test. Similarly, the 10- and 20-minute tests are identical up to 600 seconds into the test. The cumulative efficiency at that point also measures the repeatability of the test. The repeatability of the FAST measurement of efficiency for 22 individual tests had a standard deviation of 2.4% from the mean and a maximum difference of 4.3%.

FAST has been used on houses that have also been tested with Solar Energy Research Institute's very short-term monitoring procedure known as STEM. The STEM test is able to determine the overall heating system efficiency of the tested house under pre- and post-retrofit conditions. The STEM test has been used to predict normalized annual use and annual savings from furnace system retrofits. The overall heating system efficiency measured with STEM determines the appliance and distribution efficiency as a single number, while the FAST test measures the appliance efficiency by itself. When the same house was tested before and after a furnace retrofit with little or no work on the distribution system, the correlation of FAST savings predictions with STEM predictions measured the cross-test accuracy. This correlation of STEM and FAST results was done on two buildings. FAST forecast the savings on the first building to be 10.5% while STEM calculated 11.4%. On the second building FAST predicted 20.7% savings while the prediction from STEM was 21.6%. STEM should predict higher savings than FAST since it measures infiltration effects that are not measured by FAST.

Pre- and post- furnace retrofit testing of a large number of houses with FAST and with long-term statistical savings measurements such as PRISM has been considered too expensive. However, determining the defining equations for a few representative furnaces and applying those equations to a large database of furnaces can result in a prediction of savings for a retrofit program. When long-term statistical methods are applied to the same retrofit program, another measure of savings is obtained. The correlation of these two savings analyses is an indication of the agreement of long-term statistical methods and FAST. The FAST prediction of potential savings for the Sun Power furnace program, with a database of 528 furnaces, is 10.1%. The savings for the same program as measured by long-term statistical analysis range from 8% to 12%.

Future work includes statistical error analysis of the test procedure and determination of the degree FAST savings predictions can be generalized.

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