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Pacific Gas and Electric Appliance Doctor Pilot Project

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Creators of CheckMe!®

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Executive Summary

INTRODUCTION

The 1990 Fresno Appliance Doctor Pilot Project was created to investigate the potential energy and peak savings in residential air conditioners and gas forced air furnaces. The Fresno study was targeted at Pacific Gas and Electric's high bill complaint customers (Energy Cost Inquiry's or ECI's).

In the winter of 1989/90 a pilot project investigating the cause of high bill complaints among heat pump customers was initiated in PG&E's Drum Division in the area of Auburn, California. The results of the Auburn study (Pacific Gas and Electric Heat Pump Efficiency and Super Weatherization Pilot Project) indicated that substantial energy savings and peak electrical load reduction was possible from a well controlled program aimed at these heat pumps. The results indicated that a similar program directed at air conditioners was promising. The Fresno Appliance Doctor Pilot was created to examine the potential for air conditioners.

OBJECTIVES

The objectives of the Fresno Appliance Doctor Pilot were to:

(1) Identify the major problems with existing residential air conditioning installations.

(2) Identify the major problems with existing furnace installations.

(3) Determine what actions could be taken to correct those problems.

(4) Estimate the potential savings from those actions.

METHODOLOGY

Fifteen homes were selected by PG&E for the pilot project. The majority of the units belonged to high bill complaint customers with significant summer peaks. The participants averaged 3658 kWh in cooling use compared to a Fresno average of 1650 kWh. Each location was visited by a team of technicians who used specially designed forms to test, record, and repair each duct system, furnace, and air conditioner. The completed forms were reviewed by the program manager to determine that the proper work had been done and that the desired results achieved. If the review determined that the unit needed additional work, return trips were made to complete the assignment. To quantify problems with the ductwork and the building shell, each of the sites was inspected and tested using a blower door.

RESULTS

The houses investigated had major problems with the distribution system, air conditioner, and/or building shell. The cooling savings potential from air conditioning and distribution repairs exceeded 10% for every house and in a number of cases it exceeded 30%. This savings potential could be realized with duct sealing, increased airflow through the inside coil, and correcting refrigerant charge. A program based on these repairs could reduce the cooling energy use of the selected customers by an average of 24.4%, in addition to improving homeowner comfort. The repairs tested in the pilot could improve the efficiency enough to reduce the electrical load at coincident summer peak by an average of 691 watts per selected household.

The furnaces shared the duct problems with the air conditioners. In addition most furnaces needed adjustment of the fan switch to reach full efficiency. An average heating savings of 16% is projected for the pilot houses due to repairs of distribution systems and furnaces.

Problems Identified at Pilot Project.Sites

Customer complaints of high bills were traced to problems with the distribution system, the appliance, and the building shell. Ten of the fifteen units had been serviced in the last two years. The hvac contractors did not identify or solve the problems that lead to high bill complaints.

Table A lists the major problems identified at the sites in the pilot project.

Table A. Problems Identified in 15 Pilot Project Sites

	Number of Houses with Problem
AIR CONDITIONER PROBLEMS:	
Airflow less than 375 cfm/ton (dry coil) Coil Dirty or Clogged (8) Filter Dirty, Clogged, Missing (6)	10
Overcharge (Avg. 10% Excess Charge)	4
Undercharge (Avg. 20% below Correct Charge)	4
Refrigerant Leak	3
Other (Kinked Lines, Wrong Capacitor, etc.)	3
FURNACE PROBLEMS:	
Fan Off Temperature above 90 °F	9
Steady-state Efficiency less than .75	9
Gas Leak	4
Low Anticipator Setting (Causes Short Cycles)	2
Incomplete Combustion (CO Present)	1
Cracked Heat Exchanger	1
DISTRIBUTION PROBLEMS:	
Duct Leakage greater than 150 cfm	14
SHELL PROBLEMS:	
House Leakier than 0.75 air changes/hr.	5
No Wall Insulation	14
Ceiling Insulation, Less Than R-11	4
Ceiling Insulation, R-11 to R-18.9	2

Energy Savings

Table B shows the energy savings for individual repair measures, taken separately (excluding any interactive effects).

Table B. Savings Estimates for Individual Repair Measures

Repair Measure	Cooling	Kw Peak (watts)	Heating
Correct Low Airflow	7.7%	101	1.9%
Repair Overcharge	11.5%	314	
Repair Undercharge	11.8%	183	
Repair Duct Leakage	18%	527	12%
Adjust Fan Off Time (Temp)	*10%	*200	8.8%
Correct Underfired Furnace			2.9%
Reset Anticipator			2%

* Continuing to run the fan at the end of the air conditioner cycle would add sensible cooling. The increase in sensible cooling could be up to 20%. This cooling is done by returning some moisture to the inside air. Additional research is necessary to determine whether this retrofit is effective in climates in PG&E's service territory.

The individual repairs currently being considered in the package of services are listed in Table C, together with estimated costs and calculated net lifecycle benefits. The utility costs are based on PG&E rebating 75% of the on site cost to the participant.

Table C. Economic Benefit and Cost Estimates for Individual Repair Measures

Repair Measure	Est. Cost per Site	Total Utility Cost per Site	Owner Cost per Site	Net Owner Lifecycle Benefit	Net Utility Lifecycle Benefit
Correct Low Airflow	$50	$58.75	$15	$204	$52
Repair Overcharge	$100	$98.75	$25	$256	$135
Repair Duct Leakage	$250	*$242.50	$50	$1489	$1011

* includes original diagnostic work at no cost to participant.

Benefits in Table C are calculated based on an average cooling use of 3658 kWh (the average usage of the pilot units).

CONCLUSIONS

High Bill Complaints

In all cases the cooling energy use could be lowered by 10% to 30% without extreme effort. In the residences studied in the Fresno Appliance Doctor Pilot, high bill complaints were attributable to significant problems with heating and cooling equipment, the distribution system, and the building shell.

Existing Infrastructure

The Fresno pilot demonstrated that the existing hvac contractor infrastructure was not able to identify and solve the problems that led to high bill complaints. This can be attributed to a business environment that concentrates on low first cost and lowest bid. This business atmosphere results in poor installations and inadequate time available to diagnose and repair the extreme problems that exist.

RECOMMENDATIONS

The Fresno pilot project has demonstrated that substantial energy savings are available by repairing existing heating and cooling systems. Along with these savings comes an improved customer relationship and a substantive response to high bill complaints. For these reasons the following actions are recommended.

Program Implementation

1) Implement the diagnosis and repair program developed in the pilot as a service to high use air conditioning customers. Include in this program repairing duct leakage, increasing airflow, and correcting overcharge.
2) For gas forced air furnaces, implement a system to lower the fan off temperature, adjust the anticipator, and check for carbon monoxide in the flue.
3) Provide sufficient economic incentive to motivate the hvac contractor to follow the system, spending the time necessary to perform the tasks properly.
4) Provide training on the system to insure that the contractor's technicians can perform the tasks.
5) Utilize reporting, inspection, feedback, and control to insure that the system is being followed.

Evaluation and Future Development

1) Continue the submetering analysis of the pilot homes into the summer of 1991 to confirm the peak demand and summer use savings.
2) Complete a long term pre-/post-repair utility bill analysis on the homes in the pilot project and on the production program. Only through such analysis can the true effect of programs be determined.
3) Investigate the actual savings potential from adding fan run time at the end of the air conditioner cycle. Quantify the trade-off between interior humidity and sensible heat removal for climates in PG&E's service territory.
4) Determine what percentage of the residential air conditioner customer base can be serviced cost effectively with the diagnosis and repair program.

New and Replacement Residential Air Conditioner Efficiency Programs

While efficiency improvement can result in reductions in coincident peak, the most certain reductions would come from installation of higher efficiency air conditioners.

If incentives are considered for new or replacement high efficiency air conditioner installations, these installations should be held to strict criteria, including:

1) The measured airflow must be between 5% below and 15% above the manufacturer's specification.
2) The installed Energy Efficiency Ratio must be tested on site and be within 5% of the manufacturer's specification.
3) The inside coil and filter must be accessible for cleaning.
4) For new construction, the size of the unit must not exceed the size specified from Manual J calculations.
5) For replacement units, the size of the new unit must be the same or less than that of the existing unit.
6) For new construction, the ductwork must be sealed with mastic at every joint, the duct leakage tested, and known to be less than 150 cfm at 50 pa. house pressure.

SUMMARY

The PG&E Appliance Doctor Pilot Project has identified a significant source of untapped electrical and gas savings. This potential savings resides in bringing the existing cooling and heating equipment up to its designed efficiency. Field testing has proven that these repairs are economically feasible. In addition these repairs have the potential to improve customer satisfaction.

A 24.4% cooling energy savings and 12% heating savings can be accomplished by a program that diagnoses and repairs duct leakage, airflow, and overcharge on residential central air conditioners similar to those in the study.

Information developed in this project has implications for all residential air conditioners and gas forced air furnaces in PG&E's service territory. It has special significance for high bill complaint customers systemwide. In Fresno alone there were 11,856 ECI's in 1990.

Table D summarizes the projected savings, costs and benefits of a program to repair residential air conditioners similar to those in the study.

Table D. Projected Program Savings and Costs (including interactive savings effects)

Average Cooling Energy Savings	24.4%
Average Coincident Peak Reduction	691 watts
Average Heating Energy Savings	12%
Average Utility Cost	$306
Average Utility Net Lifecycle Benefit[1]	$1028
Participant Cost	$50 to $90
Average Participant Net Lifecycle Benefit[2]	$1549

1. Net benefit is gross benefit minus cost. Utility lifecycle benefit is based on reductions at on-peak and mid-peak. The analysis predicts peak reduction at super-peak (coincident peak) which is not included in this benefit calculation.
2. Participant net benefit does not include effect of the rebate.

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I. Introduction

A. PURPOSE

This report summarizes the findings from the Appliance Doctor Pilot. It is a concise listing of the major findings from the work undertaken in the summer of 1990. Details of the pilot are contained in the Appendices to the report.

B. BACKGROUND

Proctor Engineering Group (PEG) was commissioned by Pacific Gas and Electric Company (PG&E) to investigate the potential energy savings and peak reduction available by repairs to existing residential air conditioners and gas forced air furnaces. Of particular interest were PG&E customers who had complained about high bills, known as “energy cost inquiries (ECI’s)”. The Fresno division of PG&E had 11,856 ECI’s in 1990. Consequently, that division was particularly interested in programs to reduce energy use and high bill complaints. This investigation (the Fresno Appliance Doctor Pilot Project) was undertaken to determine both peak and energy savings available from a well controlled program of field repairs.

Previous studies have indicated that substantial energy savings were available both in air conditioning and gas furnace repairs.

In 1987, a field study of residential air conditioners indicated that with standard installation and maintenance, the air conditioner efficiency had degraded significantly. It estimated a lost efficiency in the order of 30% to 40%. (Neal, 1988). As a result of the Neal report, PG&E proposed an Appliance Doctor Program to recover the lost efficiency.

Hvac contractor repair of air conditioners and furnaces usually consists of fixing inoperative units so they will again cool or heat. Essentially this is bringing “dead” units back to life. In the process only “dead” appliances get attention. The philosophy of the Appliance Doctor Program was to cure “sick” units to prevent the unnecessary waste of energy. The process consisted of diagnosing the problem, applying the cure, and auditing the results.

In the winter of 1989/90 a pilot project investigating the cause of high bill complaints among heat pump customers was initiated in PG&E’s Drum Division in the area of Auburn, California. The results of the Auburn study (Pacific Gas and Electric Heat Pump Efficiency and Super Weatherization Pilot Project) indicated that substantial energy savings and peak electrical load reduction was possible from a well controlled program aimed at these heat pumps. (Proctor et al., 1990) The results indicated that a similar program directed at air conditioners might have high potential.

Since 1982, a gas forced air furnace repair program has been operating in the Rocky Mountain region. (Proctor, 1984) and (Proctor and Foster, 1986) This program has proven to save 8% to 12% of the annual heating use. In the Fresno pilot the furnace repair program procedures were combined with the procedures developed in the Auburn heat pump pilot.

With input from Proctor Engineering, PG&E hired a local heating contractor to provide two experienced air conditioning technicians and two duct repair technicians for the project. PG&E scheduled the initial site visits. Follow-up visits were scheduled by the contractor. PEG provided overall program management, including technical supervision, form design, form review, field inspection, and reporting. Proctor Engineering also provided experienced technical staff for the furnace repair work and duct testing. Work began on the first house August 23, 1990.

C. OBJECTIVES

The objectives of the project were to:

(1) Identify the major problems with existing residential air conditioning installations.

(2) Identify the major problems with existing furnace installations.

(3) Determine what actions can be taken to correct those problems.

(4) Estimate the potential savings from repairs that solve the problems.

With that information it was anticipated that a system could be designed that would:

(1) Result in improved homeowner comfort, increased efficiency of mechanical systems, and enhanced customer satisfaction.

(2) Save 20% of the space cooling energy for the selected customers.

(3) Save 10% of the space heating energy for the selected customers.

(4) Reduce coincident peak loads due to air conditioning by 10%.

II. Methodology

A. SITE SELECTION AND SCHEDULING

The city of Fresno, California was selected by PG&E for the pilot project. Fresno was selected because of its high percentage of ECI's and its cooling load of 1769 cooling degree days (65°F base). The heating degree days for that area is 2647 (65°F base). The participants were selected by PG&E based on five criteria:

- categorized as cooling Energy Cost Inquiries (ECI's) by PG&E;
- a summer peak to base ratio in the upper half of ECI's;
- a use greater than their neighbors;
- an accessible location for installation of a submeter; and
- available for the work to be done.

The total time available for the study was limited by the approaching end of the cooling season. Because time was short only "customers in the pipeline" of customer service and audit departments were considered for the program. This short time frame resulted in the 15 participants being only somewhat representative of high use ECI's. Appointments for the technician visits were scheduled by one of the auditors from the Fresno office of PG&E. The auditor also visited each house to determine its suitability for inclusion in the program.

B. GENERAL APPROACH

The approach was designed to ensure that:

1) The most prevalent problems in the test group were discovered and accurately documented.
2) The work that was done in the field accomplished its intended objective, that is, the air conditioner, furnace and distribution system actually performed better after the site work was completed.
3) The scope was sufficiently comprehensive that technicians could address the mix of problems that actually occur in the field.

In order to accomplish these tasks. The following system was used:

1) The process involved initial testing, repairs, and final testing.

2) Whenever possible production techniques developed from the Auburn Heat Pump Pilot were employed (production techniques are those designed for a high volume program).
3) All project employees and underwent specialized training at the beginning of the pilot to insure that they could perform their assignments.
4) The initial visit to the house was by a group of individuals which consisted of a team leader and two technicians. The team leader was an experienced individual with national credentials in diagnosis and repair of gas forced air furnaces, distribution systems and residential building shells. The technicians were from a local heating contractor. Since the team made repairs that influenced the airflow, this visit included pre- and post-repair testing of air conditioner efficiency.
5) The second visit was made by the program manager and a local air conditioning technician. This visit also incorporated pre-/post- testing of the air conditioner.
6) Data was recorded for every step of the process so that:
    - the condition of the air conditioner, furnace, distribution, and structure could be accurately analyzed;
    - the performance of the technician could be determined; and
    - the applicability of the testing and repair methods could be evaluated.
7) The detailed data was reviewed by the program manager who determined:
    - what feedback the technicians should receive;
    - whether or not the modifications were successfully completed and if a follow-up trip was warranted to obtain successful completion; and
    - whether the processes involved were accomplishing the desired results or needed to be streamlined or changed.
8) The program manager gave the feedback, ordered the follow-up visit or made the revisions as necessary.

C. INITIAL SITE TESTING

The initial site testing methodology was designed to answer the following:

1) What are the problems with the space conditioning systems?
2) What is the relative frequency of these problems?
3) What are the building shell problems?

The initial site tests performed on the furnace, the air conditioner, the building shell, and the ductwork determined the mechanical cause of the Energy Cost Inquiry (ECI). If these problems were present the situation was further quantified.

An interview was also conducted with the homeowner during the initial site visit. This interview assisted in determining what problems existed and their possible causes.

Furnace Testing

Initial measurements taken on the furnace included temperature rise, fan on/off temperatures, draft, input rate, and steady-state efficiency. The unit was also checked for gas leaks and the presence of carbon monoxide in the flue gas. These tests determined the initial condition of the furnace and the work necessary to bring it to safe and efficient operation.

The temperature rise is an easy measure of the airflow relative to the btu input to the furnace. When there is inadequate airflow a large temperature increase is observed as the house air passes the heat exchanger.

The fan off temperature is a critical factor in determining the efficiency of the furnace over a complete cycle. The lower the fan off temperature the higher the cycling efficiency of the unit.

Ductwork Testing

Based on the experience in the Auburn Heat Pump Pilot, duct leakage was measured by the "flow hood" test. This test utilized a blower door to pressurize the house to 50 pascals. All the registers were sealed except the largest return register. The filter was removed from that register, and a commercial flow hood computed the airflow through the register; This gave a measure of the duct leakage.

Appendix B compares two duct testing methods and details the methodology and results of the pilot.

Intensive Duct Leakage Investigation

Five of the last units were tested more intensively for duct leakage. These units were picked to represent the work of the technicians after the initial learning curve had begun to flatten out. In these units the flow hood test was run for total, return only, and supply only duct leakage. For the return and supply tests the supply system was isolated from the return by a plastic barrier at the furnace blower.

Knowing the supply/return leakage split improved the estimate of duct energy loss and duct sealing savings.

Air Conditioner Testing

Initial measurements taken on the air conditioner included airflow, cooling capacity, and electrical input. The air conditioning technician also measured the discharge line temperature, superheat, subcooling, compressor megohms, and compressor amp draw. These tests allowed the technician to determine the condition of the compressor, the adequacy of the charge, and the air conditioner efficiency.

Airflow was measured in two ways, the temperature rise test and the flow hood method. The temperature rise method is based on inputting a known amount of energy into the air stream. The energy input, the mixed supply temperature, and the mixed return temperature were measured. A single calculation, based on the heat capacity of air, determined the airflow necessary to achieve the measured temperature rise for the known input. This method is detailed in Appendix D. The flow hood method utilized a commercial flow hood to measure the flow at each return register. The flows from all the returns were summed for the total flow.

The total capacity of an air conditioner is the sum of the sensible and latent capacities. The air conditioner removes sensible heat from the house air lowering the temperature of the air. The air conditioner also removes moisture, reducing the specific humidity of the air.

The total capacity was measured after at least ten minutes of continuous running. The supply and return wet bulb temperatures were recorded. Knowing the airflow and the enthalpy change from the wet bulb readings, the total capacity in btu's was calculated.

The input wattage was determined by clocking the submeter on the air conditioner circuit.

Dividing the total capacity by the input gives the instantaneous energy efficiency ratio (EER) of the air conditioner. This efficiency is dependent on a number of parameters, including the condition of the air conditioner, the outdoor temperature, the indoor temperature, the indoor humidity, the airflow, and the amount of refrigerant charge in the unit.

$$\text{Instantaneous EER} = \frac{\text{Total Capacity}}{\text{Input}}$$

Building Shell Testing

Measurements of the building shell included a blower door test, with visual inspection of insulation levels, thermal bypasses, convective loops and wind washes.

Based on the experience in the Auburn Heat Pump Pilot, a single point test was used to estimate shell air leakage. Each of the homes was pressurized using a Minneapolis Blower Door. The fan on the blower door forced air into the house until the inside was pressurized to 50 pascals. At this point the airflow through the fan was measured. Airflow through the fan equals the air leakage out of the house. "Natural leakage rate" was field estimated as five percent of the airflow at 50 pascals.

Discussion of Potential Errors in Initial Site Testing

The flow hood duct leakage test produces a conservative leakage figure. The restriction in flow through the return grill and through the return duct reduces the pressure in the ducts to below 50 pa. This is especially true with leaky ducts and when the test register is attached to a restrictive duct. When leaky ducts are repaired the actual change in leakage at 50 pa. will be greater than the estimate from the flow hood duct leakage test. The relationship between duct pressure and duct leakage tests is discussed in Appendix B.

The temperature rise airflow test in the pilot utilized the furnace as the energy input source. This is detailed in Appendix D. A potential error when using the temperature rise method is misplacement of the thermocouple too near the heat exchanger. When this happens the thermocouple "sees" the radiant heat and gives an elevated temperature reading. Consequently a lower airflow and EER is calculated. The problem is easily avoided by correct thermocouple placement. The biggest drawback of using the furnace as the input for the temperature rise test is the necessity of running the furnace continuously for 20 minutes. If this activity takes place in the summer, it is an unappreciated activity by all but the most jovial customers.

The flow hood airflow test is limited in its accuracy. The actual flow through the air conditioner is higher than the measured flow because of return duct leaks. Additionally return registers are often of a size or in a place that the flow hood cannot be properly placed over the entire opening. This makes it necessary to estimate the total flow based on opening size. Despite these drawbacks, the flow hood test proved to be the most satisfactory for production use on air conditioners.

Measuring the total capacity of the air conditioner involves the use of wet bulb temperatures. The accuracy of a wet bulb reading is dependent on the airflow rate across the sensor. Proper placement of the sensor in the air stream produces sufficient accuracy.

All of the blower door tests were single point tests in the pressurization mode. For highly accurate results multiple point tests are necessary, however the single point test provides sufficient accuracy for a production program.

D. FIELD REPAIR

The field repair methodology is detailed in Appendix F. This methodology (Furnace Technician Procedure, Duct Technician Procedure and Air Conditioning Technician Procedure) was designed to answer the following:

1) Where energy savings potential is shown to exist, can existing hvac technicians adequately perform the tasks necessary to deliver those savings?
2) What are the key parameters, easily measured in the field, that will indicate the efficiency of a particular space conditioning system and the potential savings?
3) What is the measurable efficiency increase due to systematic repairs?

Furnace Technician Procedure

The furnace technician procedure is copyrighted material developed by Sun Power Association. It has been used to test, modify, and retest over 40,000 forced air furnaces.

The initial testing of the furnace is described in the Furnace Testing portion of this report. The results of the initial test determined the modifications applied to each unit. After the work was completed the same tests were rerun to verify the results of the repairs and modifications.

The furnace technician procedure requires four hours to complete.

Duct Leakage Procedure

The duct leakage procedure is a refinement of previous work by this author and the work of other researchers, including John Tooley (1989). It tested, sealed, and retested the distribution leakage of heating and air conditioning systems.

Initial testing of the distribution system is described in the “Ductwork Testing” portion of this report.

The procedure involved sealing the ductwork beginning with the most critical locations. The critical locations were disconnected ducts, returns open into the attic, crawlspace or walls, and large leaks behind the registers. During the procedure insulated joints were unwrapped, sealed with mastic, and rewrapped. This process is designed to eliminate the largest “catastrophic” leaks and substantially reduce the smaller “diffuse” leaks.

Repairing catastrophic duct leakage and significantly reducing diffuse leakage can be accomplished by a trained individual in four hours.

Air Conditioning Technician Procedure

The air conditioning technician procedure is a refinement of the Auburn Heat Pump Pilot testing methodology, the work of other researchers including Leon Neal (1990), and criteria developed from manufacturers’ data. It tested, modified, and verified efficiency improvements on air conditioners.

The initial testing of the air conditioner is described in the Air Conditioner Testing portion of this report. The results of the initial test determined which modifications would be accomplished on each unit.

This procedure guided the technician through the most common and easily solved problems, such as low airflow, to the more time consuming and somewhat less prevalent problems, such as improper charge. Once adequate airflow was obtained by cleaning the coil and opening registers, non-intrusive tests were run. These tests determined charge level, the condition of the compressor, and the efficiency of the unit. The level of charge was corrected by migrating charge out of the unit or adding charge to the unit. The amount added or removed was measured with a charging cylinder.

Having properly diagnosed the problems, the indicated repairs were made and the air conditioner was retested.

The procedure takes one hour for the initial test. Most units require two hours of technician time, since inadequate airflow is such a prevalent problem. Air conditioners that are overcharged take an additional two hours to repair. Units with refrigerant leaks require up to six hours of repair time.

E. SUBMETERING

Submetering was included in the pilot study in order to:

1) Provide data to create a predictive model (the hourly regression model) that estimates the potential effect of individual measures on coincident peak demand and total use.
2) Determine these units' actual contribution to the coincident summer peak diversification factor and total kW.
3) Investigate occupant thermostat management patterns and how they affect coincident peak.
4) Measure the total savings for each house.

Submetering provided actual information about the performance of these units under all conditions that occurred during the test period. It therefore provided a check of efficiency improvement predictions from one-time field tests. Submetering also recorded actual use at coincident peak to check the predictions of the hourly regression model.

All 15 residential sites were submetered to record the air conditioner kWh for every 15-minute period, both before and after energy reduction repairs were conducted. The data was analyzed for daily use, hourly use, continuous operation demand, system peak contribution, and control type.

The submetering methodology is detailed in Appendix C.

<u>Peak Savings</u>

A predictive model for peak demand reduction was developed by calculating a linear regression correlating maximum continuous air conditioner demand to hourly outdoor temperature. Another regression line describing the air conditioner use when the unit is cycling was computed; the intersection of these two lines predicts the minimum temperature that necessitates continuous operation, "Onset of Continuous Operation (OCO)". Continuous running creates the maximum sustained demand that an air conditioner will place on the utility system. This point is critical to predicting the air conditioner's demand at coincident peak. Figure 1 demonstrates an example of the hourly regression model with the continuous operation regression line, the cycling operation regression line and the OCO.

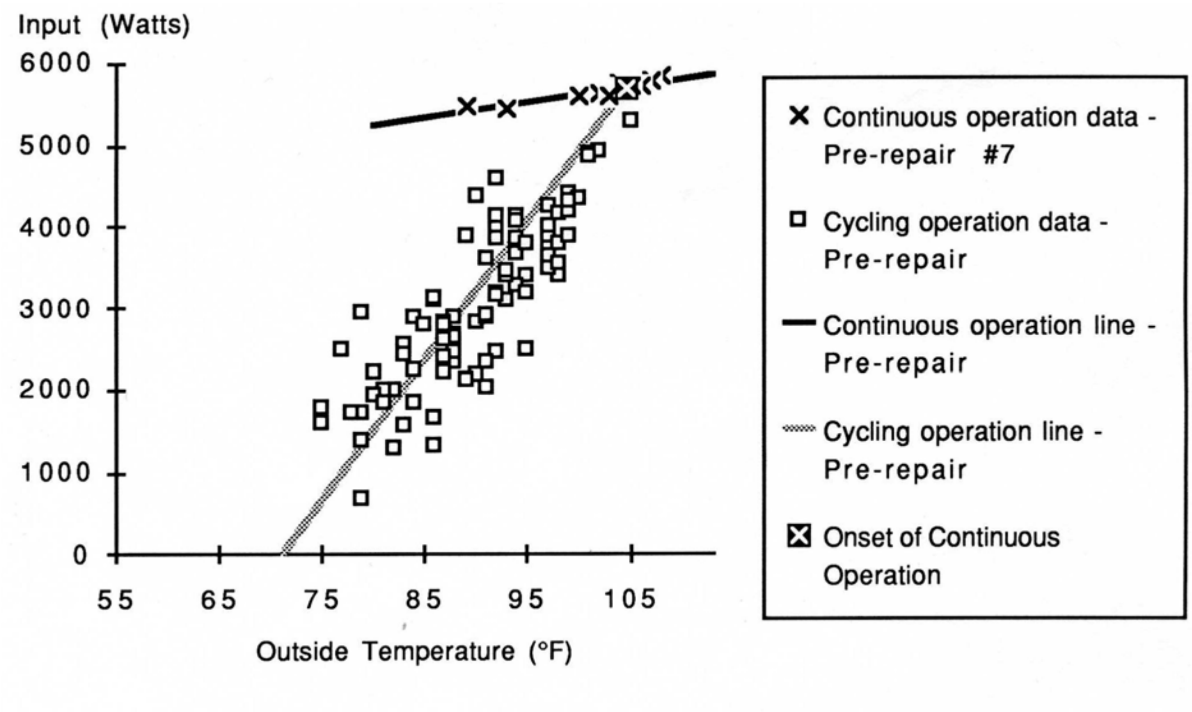

Figure 1. Hourly Regression Model

Using this predictive model, the reduction in peak energy use from the pre- to post-repair period was calculated. Changes in the continuous operation line and the cycling operation line were calculated and the effect of these shifts on peak energy use was predicted.

Overall Energy Savings

The overall savings analysis procedure creates a linear model of daily air conditioning use vs. outdoor temperature for each home and applies the model to standard weather conditions. The total energy savings attributed to the modifications is calculated by comparing the energy that would be used by the house under standard weather conditions before and after the repairs. Figure 2 shows an example of the daily use model with pre-repair and post-repair use.

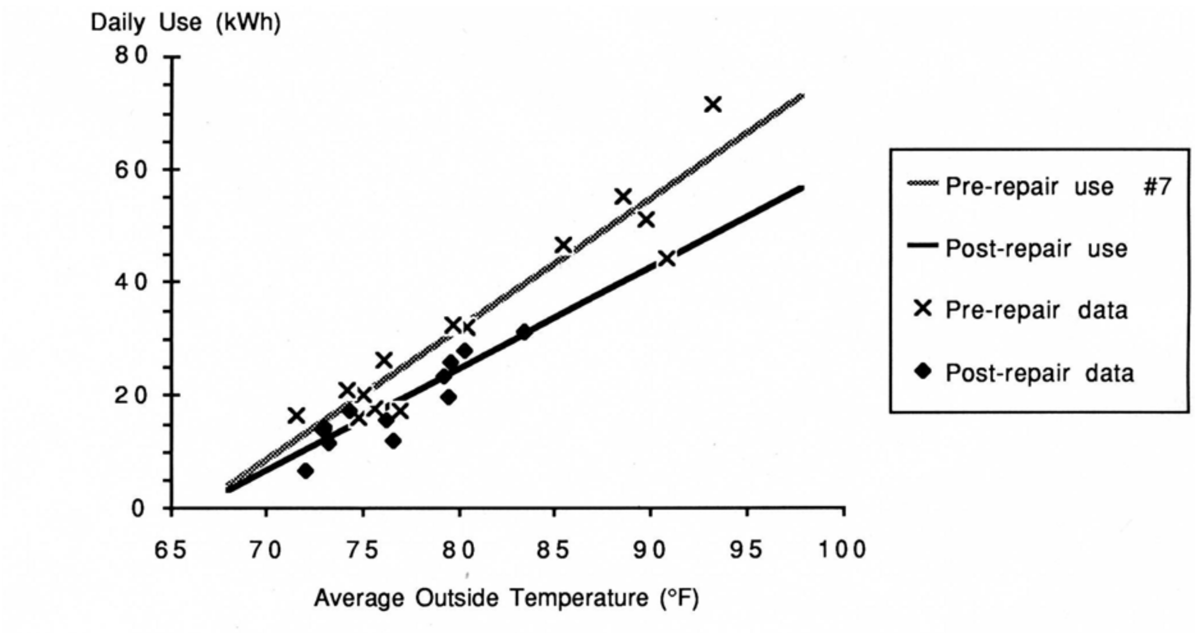

Figure 2. Daily Regression Model

F. SIGNATURE - CYCLING EFFICIENCY TESTING

The furnace and air conditioner signature tests were included in the pilot study in order to:

1) Determine the pre-/post- repair efficiencies of these units for complete (non steady-state) cycles.
2) Measure the savings associated with individual improvements so that cost effectiveness can be determined.

Furnaces and air conditioners at five homes were tested utilizing the forced air signature test (FAST). The signature test provided a rapid and reliable evaluation tool to determine the actual in-place furnace efficiency. This tool produced efficiency of the unit for entire cycles, not just steady-state conditions.

Signature testing background, methodology and results are detailed in Appendix D.

Cycle Efficiency

The cycle efficiency is the total energy delivered (or heat removed) by the furnace/air conditioner divided by the total input over an entire cycle. This was determined by measuring the output (or capacity) and the input every 15 seconds. The total energy delivered (or heat removed) up to any point in the cycle divided by the total input up to that point is called the cumulative efficiency. The cumulative efficiency vs. time gives a very repeatable "signature" of the operation of the unit. The 5-minute "signature" of the furnace in House #2 is shown in Figure 3.

The cycle efficiency is the cumulative efficiency at the time the cycle ends.

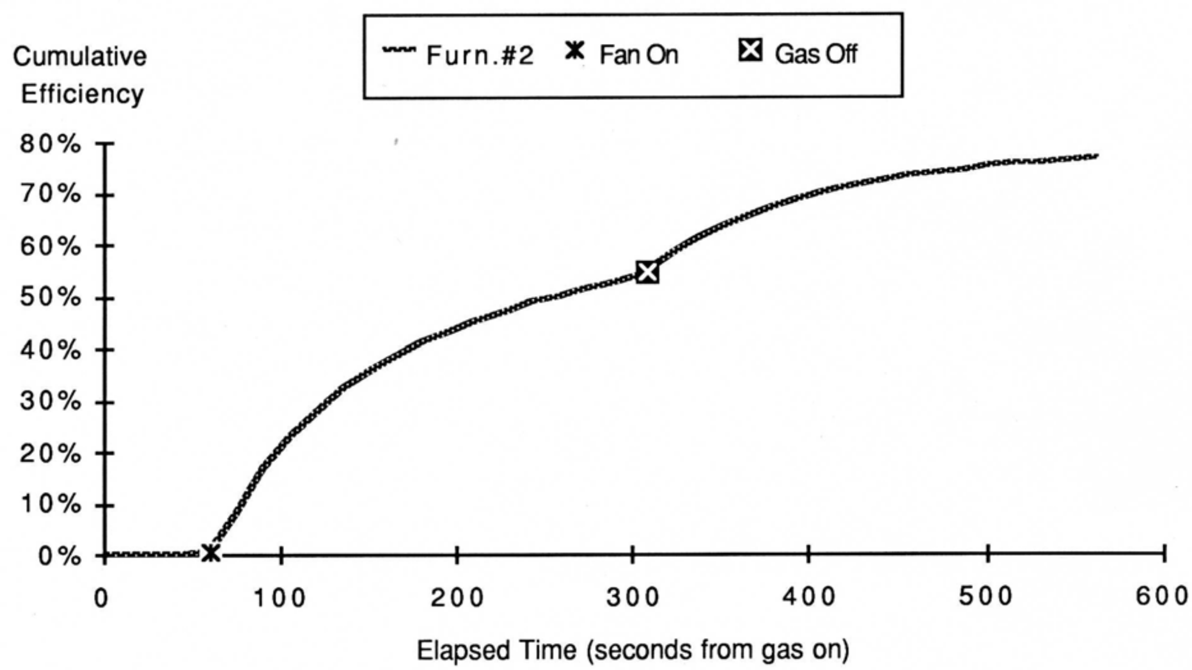

Figure 3. Cumulative Furnace Efficiency 5-Minute Cycle Furnace #2

For each furnace under each test condition (pre-/post-) a regression analysis produced an equation relating the cycle efficiency (eff.) of the unit to the delivery temperature and gas cycle length. For example, the result of the regression for furnace # 2 in the pre-repair condition is:

$$\text{Cycle Eff.} = .809 - 1.87 \times \frac{(T_{del} - 87)}{t_{cycle}}$$

<u>Where</u>

.809 = the intercept of the regression, this approaches the steady-state eff.

1.87 = the slope (a constant), efficiency decrease due to changes in fan off temperature and gas cycle length

T_{del} = temperature of the delivery air at fan off (°F)

87 = hinge point, this approaches the return air temperature at the time of the test

t_{cycle} = time from gas on to gas off (seconds) - gas burn time

The cycle efficiency was calculated by substituting the delivery temperature at fan off and average cycle time into the derived equation. This was done for both the pre- and post-repair conditions and established the pre-/post- efficiencies.

Having derived the cycle efficiencies, the savings were calculated as follows.

$$\text{Savings (\%)} = \frac{Eff_2 - Eff_1}{Eff_2}$$

<u>Where</u>

Eff_1 = initial efficiency

Eff_2 = final efficiency

III. Results

The primary results of this study are contained in this section and consist of:

- problem identification;
- effect of individual air conditioning repair items, including energy savings, reduction in continuous running input,* and reduction in coincident peak load;

* Continuous running input (CRI) is the kW input to the air conditioner when it runs without cycling.

- effect of individual furnace repair items, including energy savings;
- effect of distribution duct repair, including energy savings, reduction in continuous running input, and reduction in coincident peak load;
- identification of building shell problems;
- air conditioning coincident load and effect of thermostat management strategies;
- Appliance Doctor Pilot air conditioning energy savings; and
- Appliance Doctor Pilot furnace energy savings.

Details, important but secondary information, and extended discussion are in the following appendices :

- Appendix B - Details of duct leakage and duct sealing;
- Appendix C - Details on submetering;
- Appendix D - Details on cycling tests;
- Appendix E - Details on savings calculations.

A. PROBLEM IDENTIFICATION

The frequency of problems identified on the program houses is demonstrated in Table E. All but one of the houses studied had at least one major problem with the air conditioning system or the building shell. That house used 2160 kWh for cooling, only slightly above the Fresno ECI average (1696 kWh) and well below the average use of the study homes (3658 kWh).

Table E. Frequency of Problems Identified (by Site)

	Percent with Problem
AIR CONDITIONER PROBLEMS:	
Airflow less than 375 cfm/ton (dry coil) Coil Dirty or Clogged (53%) Filter Dirty, Clogged, Missing (40%)	67%
Overcharge (Avg. 10% Excess Charge)	27%
Undercharge (Avg. 20% below Correct Charge)	27%
Refrigerant Leak	20%
Other (Kinked Lines, Wrong Capacitor, etc.)	20%
FURNACE PROBLEMS:	
Fan Off Temperature above 90 °F	60%
Steady-state Efficiency less than .75	60%
Gas Leak	27%
Low Anticipator Setting (Causes Short Cycles)	13%
Incomplete Combustion (CO Present)	7%
Cracked Heat Exchanger	7%
DISTRIBUTION PROBLEMS:	
Duct Leakage greater than 150 cfm	93%
SHELL PROBLEMS:	
House Leakier than 0.75 air changes/hr.	33%
No Wall Insulation	93%
Ceiling Insulation, Less Than R-11	27%
Ceiling Insulation, R-11 to R-18.9	13%

B. AIR CONDITIONING REPAIRS

The major effect of the field repairs on the air conditioners was to bring the critical performance parameters of airflow and charge to near the design for each parameter. As a result, the largest efficiency improvement occurred on air conditioners that were operating the furthest from their design conditions.

Airflow

Airflow should be 425 to 450 cfm per ton through a dry coil. This will give the proper 400 cfm per ton through the unit when the air conditioner is running and the coil is wet. A summary of the initial airflow in cfm/ton is shown in Figure 4.

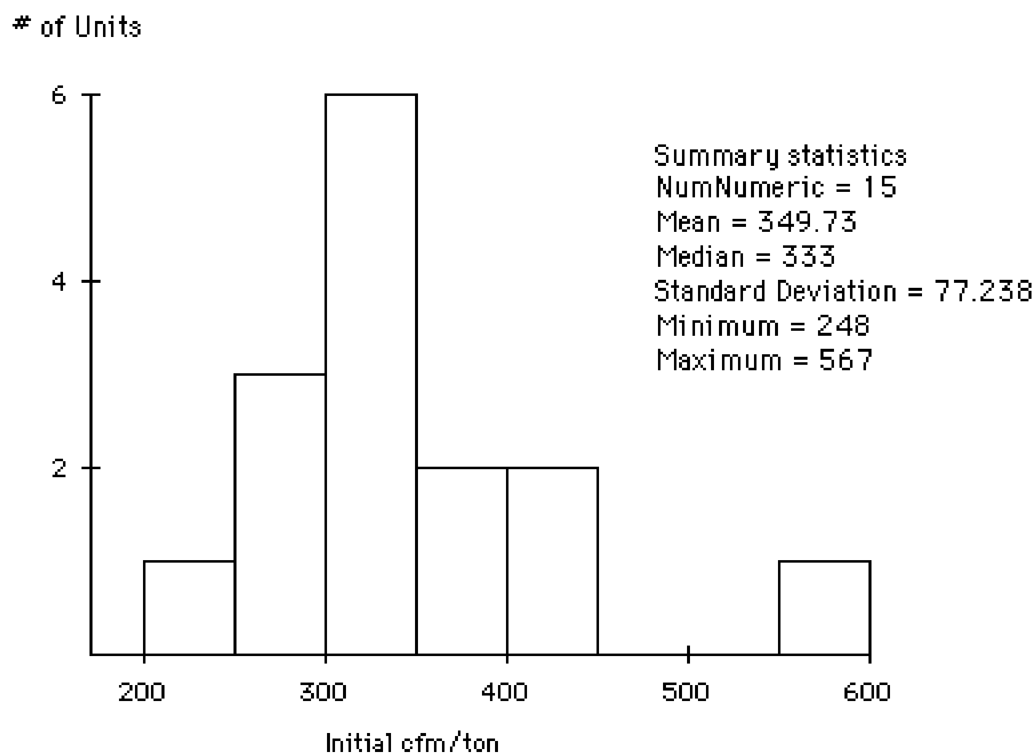

Figure 4. Statistical Summary of Initial Airflow (AC)

Low airflow was the most prevalent air conditioner problem in the study. The primary cause of low airflow was dirty inside coils. One coil was so dirty and wet that mold was growing on the coil. An air conditioning technician had been to the house recently to diagnose the problem. He had correctly diagnosed low airflow but rather than cleaning the coil, he sold the homeowner a higher horsepower motor for her indoor fan.

The most effective repair for low airflow is cleaning the inside coil. On direct drive motors, the blower is usually wired to high speed operation in the cooling mode. Belt driven blowers, on the other hand, usually have the drive pulley incorrectly adjusted. In those cases adjusting the pulley to higher blower speed can be effective. In the pilot, these changes to the ten units with low airflow increased airflow by 16%. A summary of the final airflow in cfm/ton is shown in Figure 5.

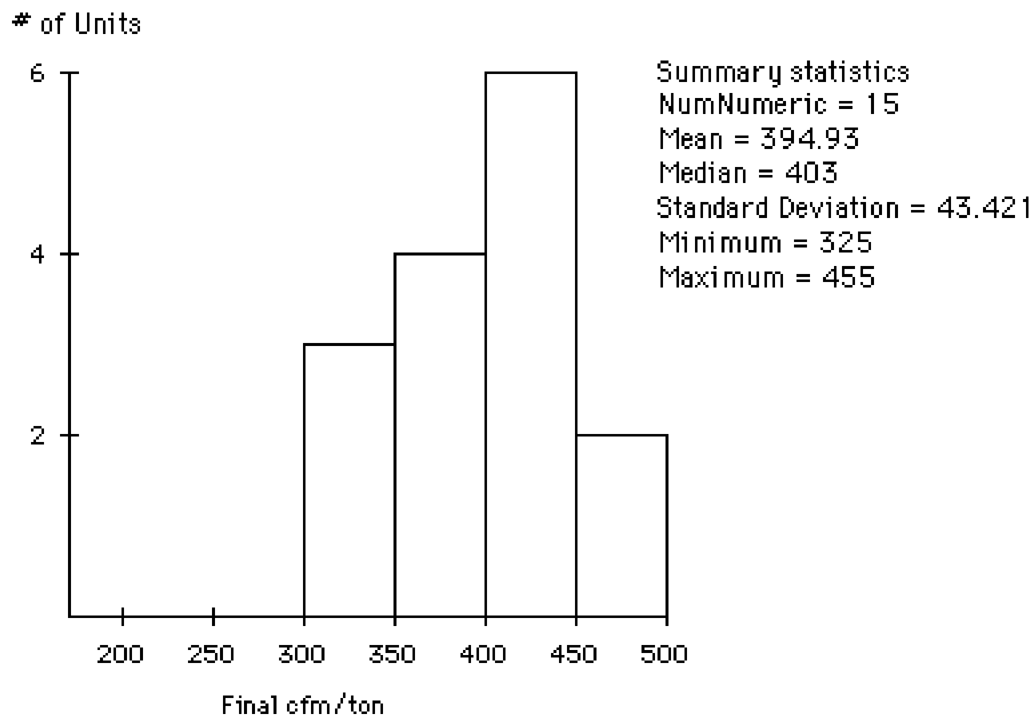

Figure 5. Statistical Summary of Final Airflow

Low airflow is a substantial problem for air conditioners. The estimated cooling savings from coil cleaning and limited blower speed adjustment is 7.7% for the units that had a low flow problem.

Increasing the airflow of an air conditioner has two effects. It improves the efficiency of the unit and increases the CRI (continuous running input). CRI is the kW input to the air conditioner when it runs without cycling. The CRI increases because cleaning the coil increases the load on both the inside fan and the compressor. Repairing a low flow condition (dry coil cfm/ton < 375) is estimated to raise the CRI by an average of 5%.

The coincident peak is determined by the efficiency for units in the cycling mode and by the CRI for units running continuously. The average coincident peak for studied units with low airflow is projected to fall 101 watts due to repairs.

Under normal circumstances, low airflow is likely to continue to go unrepaired unless it is due to a clogged filter. Reasons for the lack of repair are:

1) Technicians do not regularly test for airflow, in spite of the fact that the tests for proper charge are only meaningful when there is proper airflow.
2) Indoor coils are often accessible only with extreme perseverance.

3) Technicians do not regularly work on ducts, so crushed and kinked ducts are not repaired.

High airflow was found on one unit in this sample. That unit had massive return leaks through open wall cavities into the attic. Those leaks provided very little restriction to the suction side of the blower; as a result higher than normal airflow occurred. When the airflow is too high the results are excessive noise, less moisture removal and increased duct leakage.

Improper Refrigerant Charge

Improper charge occurred on 56% of the units. Undercharge and overcharge were evenly distributed. The average overcharge was 10%, while the average undercharge was 20%.

In the field, most technicians make the determination of proper refrigerant charge through guesswork. One of the common techniques is to “feel the lines” to determine charge.

Checking for correct refrigerant charge is a task that is straightforward given proper training and adequate time. For the most common system (capillary tube flow control) charging is a well defined process. A single generic chart can be used to determine whether the unit has proper superheat - indicating the correct level of charge. This method is quite accurate, but it takes more time than “feeling the lines.” Units with expansion valve (TXV) flow control should be charged to the proper head pressure determined by the manufacturer’s chart. Suction pressure is also monitored in this procedure. Manufacturers’ charts are often missing in which case the unit can be charged to 10°F subcooling. Pumping down the system and weighing in the charge is accurate but time consuming.

It is not surprising that many of these units have an incorrect charge for the following reasons.

1) When the technicians install and remove their gauges it is easy to let refrigerant escape. This is especially a problem on units with liquid line taps.
2) When parts of the system are replaced and repairs are hastily made, brazing connections to the new part are often leaky.
3) Technicians often add refrigerant without finding the cause.

During this project all but one of the identified refrigerant charge problems were repaired. On that unit there were numerous leaks in the coil, a cracked furnace heat exchanger and a damaged compressor. That unit needed to be replaced.

Proper charging is estimated to save 11.5% on overcharged units and 11.8% on undercharged units. Correcting refrigerant charge increases the CRI for undercharged units by 11.6% and decreases it by 1.2% on overcharged units.

The average coincident peak for undercharged air conditioners is projected to fall 183 watts. For overcharged units the reduction is approximately 314 watts. These estimates are based on a typical undercharge of 20% and typical overcharge of 10%.

Air Conditioning Fan Off Potential Savings

At the end of a typical air conditioning cycle when the compressor shuts off so does the inside fan. The efficiency of the air conditioner is affected, if the cycle is extended by delaying the fan off. This is detailed in Appendix D.

In hot dry climates evaporative coolers can effectively provide substantial space conditioning in hot weather. In hot wet climates it is necessary to not only cool the inside air but also remove substantial moisture. Many air conditioners are designed to accomplish the latter task. In hot climates with moderate moisture, some evaporative cooling could be added to the end of the air conditioning cycle. This could be accomplished by running the inside fan at the end of the normal air conditioning cycle. This would be equivalent to installing an air conditioner with a higher sensible heat ratio. The additional sensible cooling and improved sensible capacity to input ratio (“sensible EER”) is substantial as shown in Figure 6.

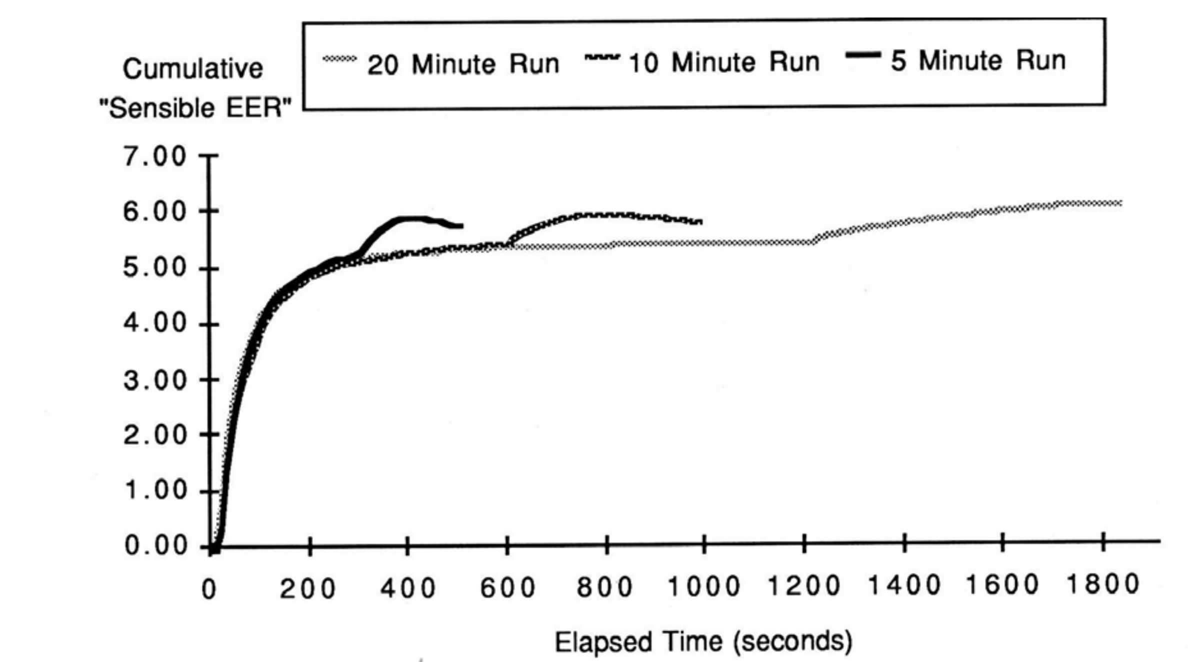

Figure 6. Increase in Sensible Cooling by Running Inside Fan

Running the fan at the end of the air conditioner cycle potentially could save up to 20% of the cooling energy. Previous research (Khattar et al., 1985) into continuous running fans concluded that, “It can also prompt lower temperature settings, which would be counterproductive to energy savings.” Research in PG&E’s service territory is required to determine the indoor humidity effects, occupant response, and actual savings potential of running the fan for some period after the compressor shuts off.

Running the fan at the end of the cycle would have no effect on CRI. If an average 10% savings was accomplished, the average coincident peak could fall as much as 200 watts.

C. FURNACE REPAIRS

The primary effect of the field repairs on furnaces was to lower the fan off temperature - the most effective adjustment available for a forced air furnace. As with the air conditioners, the largest efficiency improvement occurred on furnaces that were operating the furthest from their optimum settings.

Airflow

Intensive furnace cycle testing has demonstrated that fossil-fueled forced air furnace efficiency decreases with reduced airflow. (deKieffer, 1990). The estimated heating savings from coil cleaning and limited blower speed adjustment is 1.9%.

Fan Off Control

At the end of a furnace cycle the fan continues to run after the gas is off. This delivers additional heat to the house. If the cycle is extended by delaying the fan off the efficiency of the furnace is affected.

Delaying the fan off will scavenge usable heat from the heat exchanger and improve cycling efficiency. Previous studies (Proctor, 1984; Proctor and Foster, 1986) have shown that a measured fan off temperature of 90°F is acceptable in residences when the occupants are informed about the savings resulting from this adjustment.

In this study, the furnace fan off temperatures were adjusted too high on 60% of the units. The effect of this misadjustment is to decrease the cycling efficiency of the furnace significantly. When the furnace is installed it is common for the installer to adjust the fan off temperature to 110°F or higher in order to preempt customer complaints of cool air at the end of the cycle. In addition, the adjustment is made based on the fan switch scale which is inaccurate.

Readjustment was aimed at producing a measured delivery temperature of 90°F when the fan shut off.

On the dual-packs in this study, a combination of conventional thermal fan switches and time delay fan switches were found. The fan off settings were adjusted by resetting the thermal switches or adding an additional time delay relay.

The cycling tests showed that the furnace efficiency (excluding duct losses) was essentially a linear function of the fan off temperature and gas burn time (fan off temperature determines how long the fan runs at the end of the cycle by scavenging heat from the heat exchanger). The relationship between gas burn time, fan off temperature, and efficiency is demonstrated graphically in Figure 7.

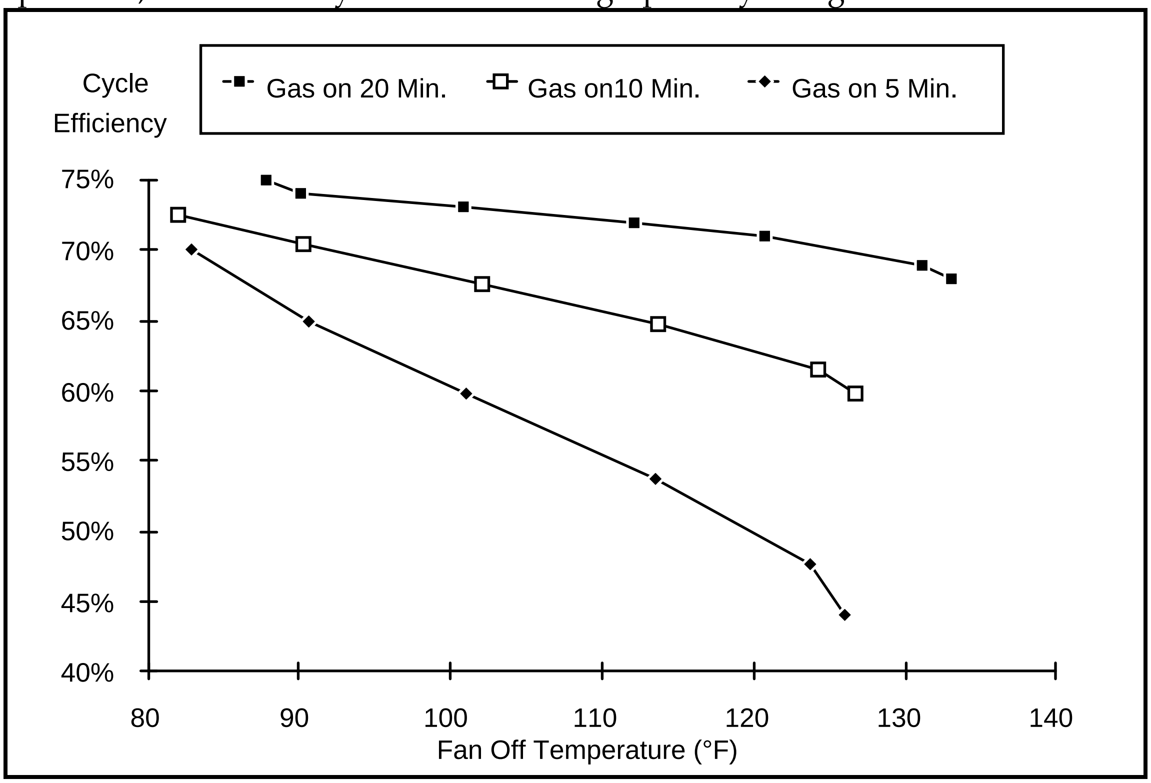

Figure 7. Fan Off and Cycle Length Effect on Efficiency - Furnace #5

Figure 7 is typical of the furnaces in the study. From this figure the following can be observed:

1) As the fan off temperature was lowered the efficiency of the furnace improved substantially.
2) The efficiency improvement from lowering the fan off temperature was greatest for short cycles.
3) Longer cycles produced higher furnace efficiencies, however the effect was diminished as the fan off temperatures were lowered.

4) It required a substantial increase in cycle length to obtain a significant furnace efficiency gain.

This series of curves can be represented by the equation:

$$\text{Cycle Eff.} = .774 - 1.76 \times \frac{(T_{del} - 69)}{t_{cycle}}$$

Where

T_{del} = temperature of the delivery air at the end of the cycle(°F) - fan off temperature

t_{cycle} = time from gas on to gas off (seconds) - gas burn time

Changing the furnace fan off temperature is estimated to save 4.4% of the heating energy use for every 10°F reduction. For an average reduction of 20°F the savings would be 8.8%

Furnace Steady-State Efficiency

The steady-state efficiency of a modern gas forced air furnace is determined primarily by the heat exchanger design and the percentage of excess air present. Smaller efficiency changes occur due to the temperatures of the combustion and the house air as well as the flow rate of house side air.

Excess air is mostly secondary combustion air and the volume is not adjustable. The percentage of excess air, however, depends on the actual gas input rate of the furnace. When a furnace is underfired the percentage of excess air is high; this lowers the steady-state efficiency.

Six of the nine units with low steady-state efficiency were underfired. If the input rate was adjusted on these units to the rated values, there would be an average heating fuel savings of 2.9%.

Gas Leak

Four of the furnaces (27%) had gas leaks. Data from previous studies including a study of 1,000 furnaces (Frey et al., 1989) shows that gas leaks would be expected on 8.3% of the units. The high frequency of gas leaks on these units may be due to the placement of most of these furnaces on the roof. With this placement the occupants of the house are very unlikely to smell the gas leak.

Anticipator Setting

Signature testing shows that the gas burn time of the furnace is a critical factor in determining the efficiency of the furnace. The gas burn time is affected by the anticipator setting. When the anticipator is set too low, burn time is short and cycling efficiency is poor.

High anticipator settings are also detrimental. When the anticipator is set too high the long burn time overheats the house and increases building heat loss.

Two units had low anticipator settings and six had high settings. Increasing the anticipator setting on the two low units to the correct values will result in an average heating fuel savings of 2%. The savings for reducing the settings on units with high settings is not adequately documented.

Incomplete Combustion

One house had incomplete combustion resulting in large amounts of carbon monoxide in the flue gas (full black with one pump of the Monoxor). This single occurrence represents 7% of the sample group which is close to the 5% expected from the 1,000 furnace data base.

Incomplete combustion normally goes undetected because technicians do not have the equipment or training to perform the simple test for CO in the flue gas. This incomplete combustion has two effects. First, the presence of significant (greater than 100 ppm) CO in the flue makes it possible for CO to enter the structure through some venting failure. This has serious or even fatal consequences to the occupants. Second, the presence of significant CO in the combustion products indicates that the burn is incomplete. This can substantially lower the efficiency of the unit.

In the single case found in this study, the savings from obtaining a complete burn and eliminating CO was 19.1%.

Heat Exchanger Cracks

One furnace had a cracked heat exchanger. The production furnace program has a frequency of cracked heat exchangers of approximately 2%.

The heating industry does not often miss diagnosing a heat exchanger problem since there is significant economic incentive to find it (a cracked heat exchanger usually results in the installation of a new furnace).

D. DUCTWORK REPAIRS

Duct leakage was the most prevalent problem in the studied homes. The average initial duct leakage corrected to 50 pa. pressure was 419 cfm. Results from the flow hood duct leakage tests are shown in Figure 8.

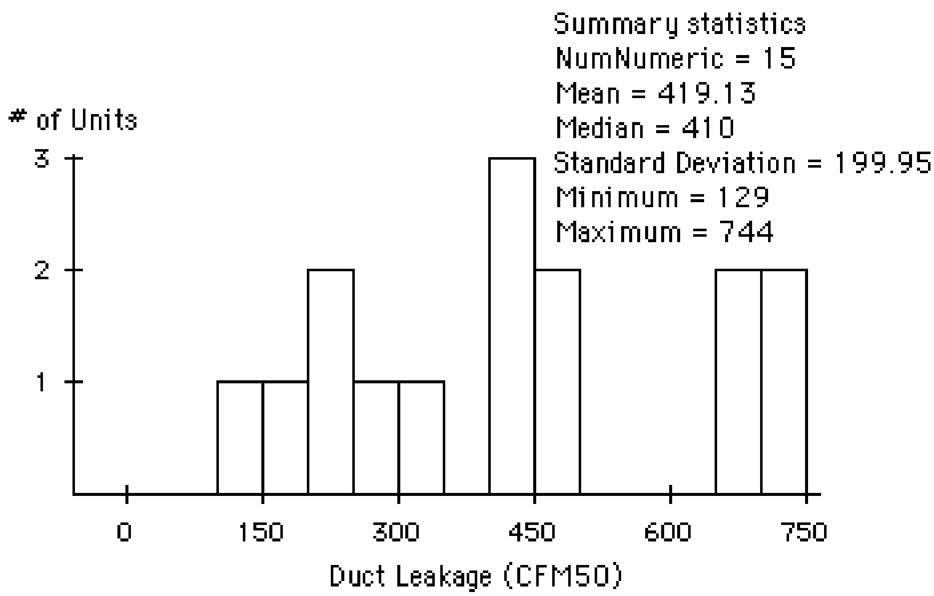

Figure 8. Statistical Summary of Duct Leakage

Tooley and Moyer (1989) measured duct leakage in 23 Florida homes. The average duct leakage in that study was a similar 406 cfm.

In the Fresno Appliance Doctor study, duct leakage (CFM50) averaged 14.7% of the total house leakage. This number is similar (considering sample size) to the 18% that was found on a 40 new home statewide sample by Berkeley Solar Group (1990). It is also similar to a 11.7% found in a 61 home study by Cummings et. al. (1990).

While duct leakage was 14.7% of the total house leakage, the effect is much larger than this percentage implies. The duct leakage is of higher importance than other leakage sites in the home for three reasons:

1) The highest pressure differential across leakage sites occurs at ductwork cracks when the inside fan is on (pressures of 50 pascals are common). For homes in the study these pressures occur during 29.9% of the cooling hours.
2) Leaks in the supply ducts expel air that is cooled below house air temperature. A 10% supply duct leak to the outside is a 10% cooling capacity loss.

3) Superheated attic air leaking into the return system further increases the cooling load.

As a result of the above three items the average cooling load increase from duct leakage was approximately 25% for the study homes. The corresponding heating loss was 16.2%.

The five duct systems studied in detail had higher average leakage than the study as a whole. Their average cooling load increase due to duct leakage was 29%. The results of the intensive duct leakage investigation are contained in Appendix B.

After the initial learning period, technicians were able to seal almost 60% of the measured duct leakage. In a number of instances the location of the duct leak could be determined, however that location was inaccessible to repair. Nevertheless, with proper training and feedback it is possible for four hours of work on the ducts to achieve an average 65% reduction in duct leakage. Work by Tooley (1990) in Florida produced an average reduction in duct leakage of 67%. The resulting cooling savings measured by Cummings (1990) was 18%.

Based on the empirical data in the Cummings study, the estimated cooling savings for duct repair is 18%. The corresponding heating savings is 12%.

Duct sealing has little effect on continuous running input. However the reduction in peak is substantial. The average coincident peak for the study units is projected to fall 527 watts.

E. BUILDING SHELL PROBLEMS

All but one unit lacked wall insulation and 40% had R-11 or less ceiling insulation. The lack of wall and adequate ceiling insulation is somewhat a function of the age of these structures. Only one unit was built after Title 24 standards were in place. In addition, many of these units were observed to have inadequate attic ventilation for this climate.

Excessive air infiltration and duct leakage were the most common shell problems in the homes studied. The natural air change estimate averaged .68 air changes per hour. This is very close to the .67 natural air change estimate from the 51-unit heat pump study of predominantly post-Title 24 homes.

F. AIR CONDITIONING COINCIDENT LOAD

The coincident load and the effect of thermostat management patterns were studied through the submetering analysis. Two participants no longer used their air conditioners because of their perception that the bills were too high. These two units were dropped from the analysis except as noted.

Savings at coincident peak (called super-peak in PG&E terminology) was studied. Savings at other "peak" hours would exceed the savings calculated for coincident peak. Peak savings is the difference between the pre- and post-repair peak load. These values can be derived from a predictive model based on submetered data or directly measured by the submeter if it is in place when the peak occurs.

Pre-Repair Peak

The submetered data provided adequate pre-repair information with which to model eleven of the houses. The most recent PG&E system peak of 19,400 megawatts occurred on 8/9/90 at 15:00. The model predicted a peak use for study houses on 8/9/90 of 59.51 kW. The actual peak use for these homes was 61.29 kW. The prediction is within 3% of the actual peak. Predicted and actual peak use for the eleven houses is shown in Figure 9. (The meter was not installed on House #11 until 8/10/90. The actual meter readings for 15:15 through 17:00 on 8/10/90 are included in the total.)

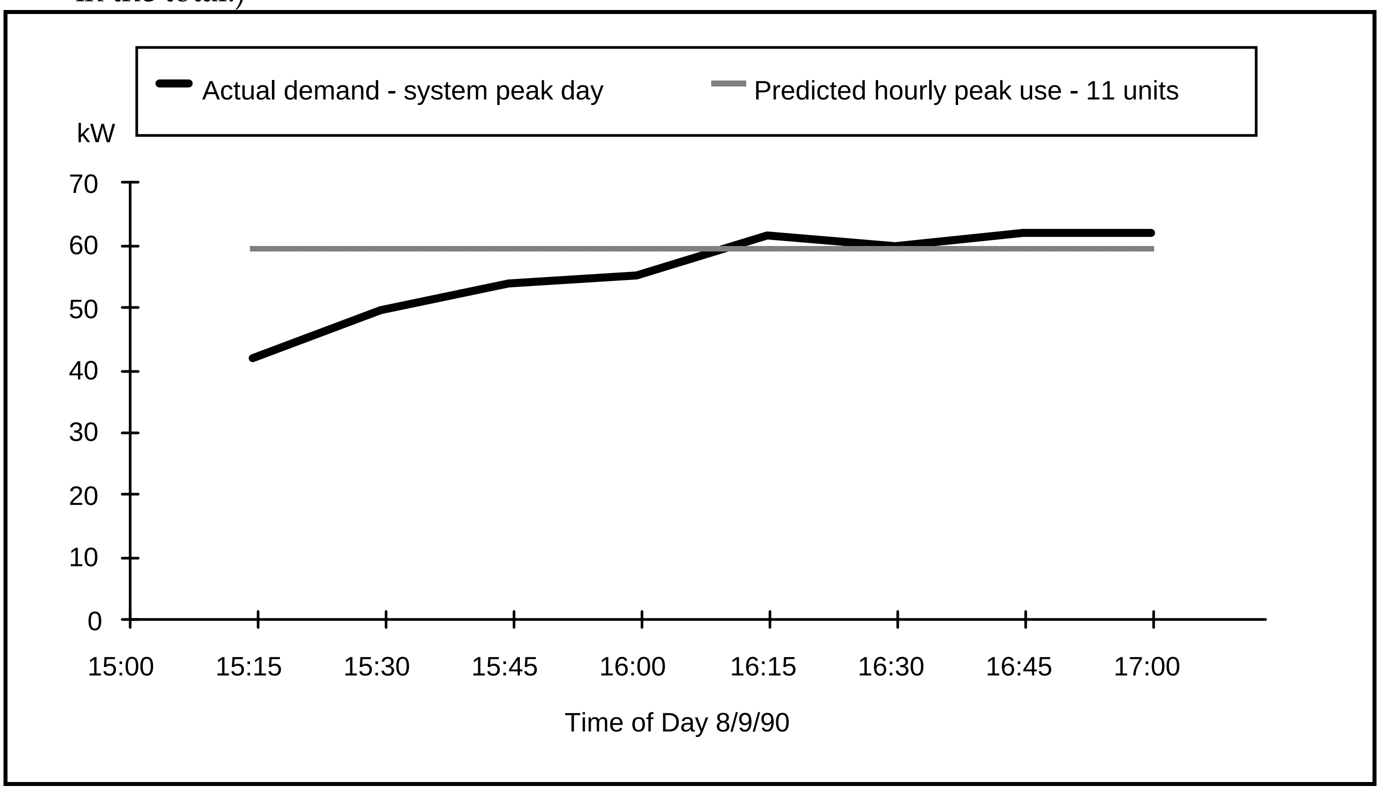

Figure 9. Comparison of Predicted AC Peak Demand to Actual Peak Demand

The peak diversification factor describes the fraction of the maximum (continuous running) load that can be expected to be on line during a peak hour. The peak diversification factor used by PG&E for residential air conditioning is .49. The test units exhibited significantly higher diversification factors at coincident peak, as reported in Table F.

Table F. Peak Diversification Factors

Standard Peak Assumption PG&E Systemwide	0.49
Coincident - Predicted from Study	0.96
Actual 16:00 (8/9/90)	0.99
Actual 15:00 (8/9/90)	0.80
Actual 15:00 (8/9/90) including two unpredictables	0.76
Actual 15:00 (8/9/90) including two unpredictables and two totally unused units	0.67

Post-Repair Peak

The post-repair time period did not contain temperatures warm enough to predict the post-repair peak. The meters remain in place and data from the summer of 1991 will be input into the model. The post-repair peaks for this report were estimated by recalibrating the pre-repair models for each unit. This estimation is described in detail in the methodology section.

Peak Savings

Table G shows the coincident peak reductions for individual repair measures, taken separately (excluding any interactive effects).

Table G. Peak Reduction Estimates for Individual Repair Measures

Repair Measure	Kw Peak (watts)
Correct Low Airflow	101
Repair Overcharge	314
Repair Undercharge	183
Repair Duct Leakage	527
Adjust Fan Off Time	200 (potential)

Thermostat Control Strategies

The occupants of the test houses utilized a variety of thermostat control strategies:

1. Six of the houses used off/on control - manually switching the thermostat on when the occupant wants it cooler and off when s/he considers it cool enough. This is accomplished with the off-cool switch on the thermostat or by adjusting the set point of the thermostat up/down.
2. Three of the houses used daily set up/set down control - a consistent pattern of setting the thermostat up in the evening and down at some time during the day, with only occasional minor adjustments of the thermostat.
3. Four of the houses used constant temperature setting control - setting the thermostat at one temperature and nearly always leaving it untouched.
4. Two of the houses did not use their air conditioners at all.

Extreme examples of off/on control and constant temperature control are shown in Figures 10 and 11.

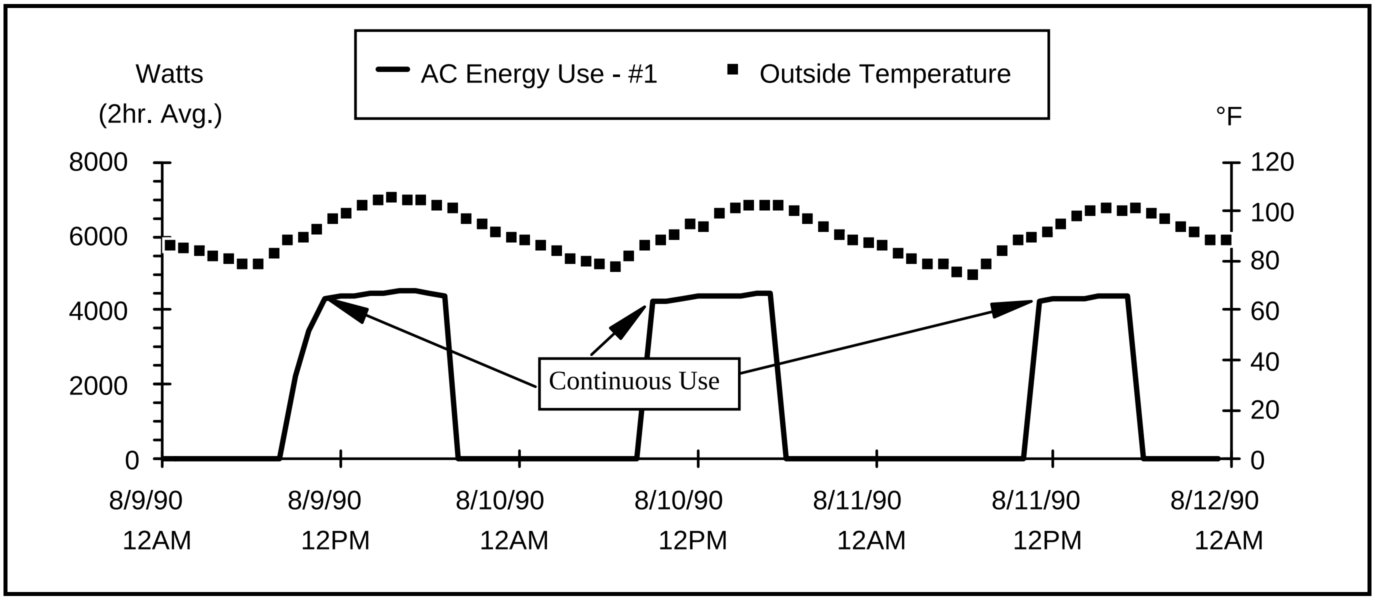

Figure 10. Off/On Thermostat Control Pattern - Air Conditioner #1

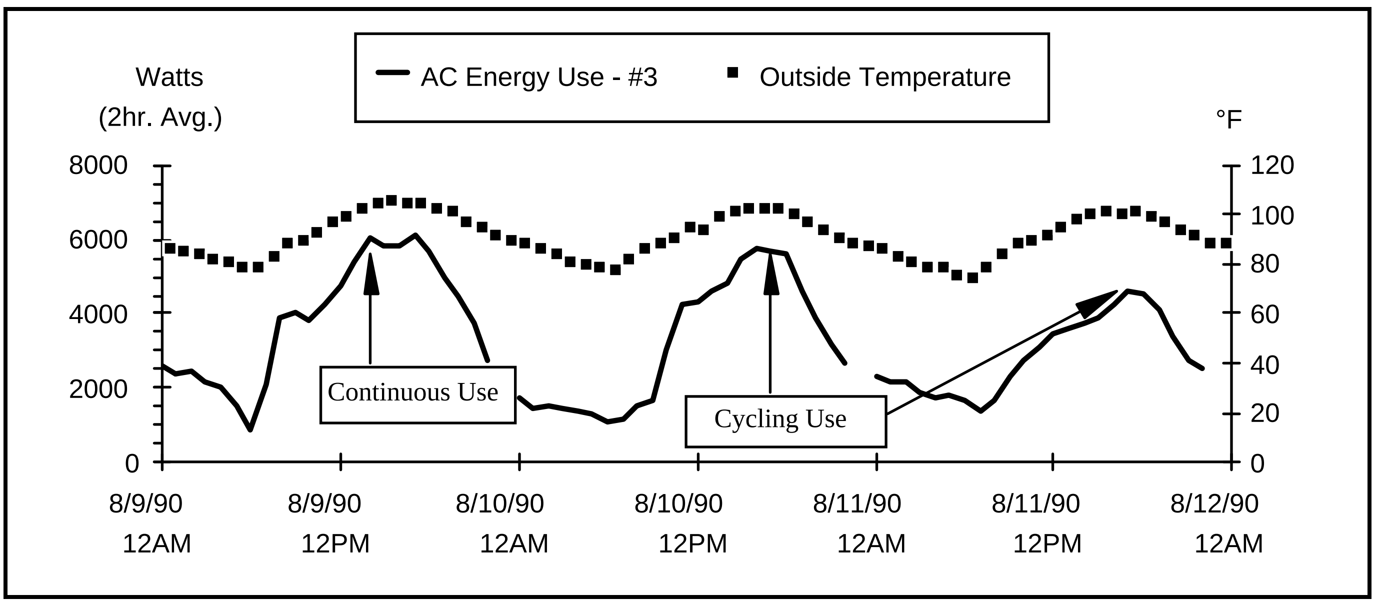

Figure 11. Constant Temperature Thermostat Pattern - Air Conditioner #3

For on/off or set up/set down control patterns the unit may operate continuously at any temperature. These control patterns impact the model by lowering the onset of continuous operation (OCO).

G. APPLIANCE DOCTOR PILOT AIR CONDITIONING SAVINGS

The daily use analysis described in the methodology section derived the weather corrected total savings.

Eight houses had adequate predictable pre- and post-repair use for the regression to be meaningful (R^2 is greater than .70). Post-test weather conditions did not include the extreme high temperatures that occurred during the pre-repair period. This results in fewer days with the air conditioner running and less reliability in the regressions. The submeters remain in place. Data from high temperature days in the summer of 1991 should produce adequate data to refine the analysis.

Savings for the eight houses are reported in Table H.

Table H. Weather Normalized Savings
Submetered Data

Air Conditioner #	Cooling Savings
3	17.98%
5	31.59%
6	9.56%
7	22.35%
8	29.40%
11	21.57%
12	4.65%
15	-11.22%

House #15 showed negative savings. This house was manually controlled in the off/on mode; the control mechanism may be responsible for the negative savings. Other occupancy factors may have led this household to use the air conditioning more during the post-repair period.

H. APPLIANCE DOCTOR PILOT HEATING ENERGY SAVINGS

The FAST (forced air system test) data for five furnaces was analyzed as described in the methodology section and Appendix D. The results give substantial information about furnace performance and savings available by adjusting the fan off temperature for these furnaces.

Cycling Efficiencies

The furnace steady-state, cycling, and overall efficiencies are shown in Figure 12.

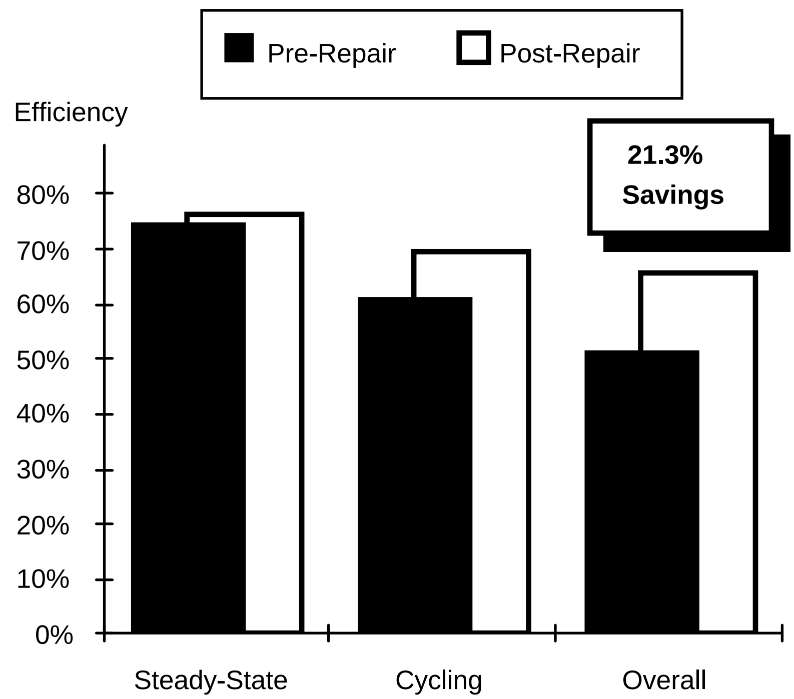

Figure 12. Efficiency Improvement from Furnace Repairs Signature Test Units

This figure graphically illustrates the effect of modifications to the furnace. The change in steady-state efficiency was primarily due to the increased airflow. The savings measured by the steady-state efficiency was 1.9%. The change in cycling efficiency includes the steady-state improvement and also the fan off temperature adjustments. The savings measured by cycling efficiency was 11.5%. This is in the range of 8% to 12% measured previously in the production furnace program. The overall efficiency is based on the cycling efficiency and the average distribution efficiency calculated for units in the study. This does not include conductive duct losses which would further reduce the overall efficiency. Even without that loss the overall efficiency was approximately 51.5% before repairs. Class B monitoring in the early 80's measured similar overall furnace efficiencies for gas fired forced air furnaces (SERI, 1983); (SERI, 1984). The post-repair overall efficiency captures the sum of airflow improvements, fan off adjustments, and duct leakage reductions.

Based on eliminating 65% of the duct leaks, the overall savings calculated for these five units was 21.3%.

Incomplete Burn - (CO)

One signature test unit was removed from the above analysis because it had massive carbon monoxide. This made the standard flue gas analysis of steady-state efficiency invalid. The steady-state efficiency was determined by measuring the flow through the unit using the flow hood and adding the measured 230 cfm return leak. From the measured airflow and temperature rise, the steady-state output was calculated. The ratio of steady-state output to input (s.s. eff.) for that unit was initially 60.8%. After the furnace was repaired and CO eliminated the s.s. eff. was 75.1%. The savings from obtaining a complete burn was 19.1%.

I. APPLIANCE DOCTOR PROGRAM - ECONOMIC SUMMARY

The savings estimates and net lifetime benefits in this report are calculated using empirical data whenever possible. Net lifetime benefit was calculated by PG&E using the DSSTRATEGIST software. The savings estimation process and benefit analysis inputs are described in Appendix E.

The calculation of estimated savings for the total program can be summarized as:

1) The savings for each individual house in the sample is calculated "in series," i.e. the savings are not additive, but discounted by the savings that has occurred due to other program items when applicable to that house.
2) The savings for all fifteen houses in the sample are then averaged producing an unweighted average savings for the program.

Overall Savings, Cost and Benefits

Table I shows the projected energy savings, costs, and net lifecycle benefit for a 3000-home program consisting of air conditioning diagnostics and duct sealing, with repair of low airflow on 2000 units and correcting overcharge on 750 units. Interactive effects are included.

Table I. Projected Program Savings, Peak Reduction, and Costs (including interactive savings effects)

Average Cooling Energy Savings	24.4%
Average Coincident Peak Reduction	691 watts
Average Heating Energy Savings	12%
Average Utility Cost	$306
Average Utility Net Lifecycle Benefit[1]	$1028
Participant Cost	$50 to $90
Average Participant Net Lifecycle Benefit[2]	$1549

1. Net benefit is gross benefit minus cost. Utility lifecycle benefit is based on reductions at on-peak and mid-peak. The analysis predicts peak reduction at super-peak (coincident peak) which is not included in this benefit calculation.
2. Participant net benefit does not include effect of the rebate.

Itemized Savings, Costs and Benefits

In order to plan the mix of measures included in a particular program it is necessary to look at the individual savings, costs, and benefits. Table J indicates the energy savings and peak reduction for individual repair measures, taken separately (excluding any interactive effects).

Table J. Savings & Peak Reduction Estimates for Individual Repair Measures

Repair Measure	Cooling	Kw Peak (watts)	Heating
Correct Low Airflow	7.7%	101	1.9%
Repair Overcharge	11.5%	314	
Repair Undercharge	11.8%	183	
Repair Duct Leakage	18%	527	12%
Adjust Fan Off Time (Temp)	*10%	*200	8.8%
Correct Underfired Furnace			2.9%
Reset Anticipator			2%

* Research in PG&E's service territory is required to determine the indoor humidity effects, occupant response, and actual savings potential of delaying fan off past compressor shut down.

Table K. shows the net benefits of individual savings for both the homeowner and the utility. This is based on a program with strong quality control and a 75% customer rebate of on site costs. The net benefit is the gross benefit minus the cost.

Table K. Benefit and Cost Estimates for Individual Repair Measures

Repair Measure	Est. Cost per Site	Participant Contribu-tion	Total Utility Cost	Net Owner Lifecycle Benefit[1]	Net Utility Lifecycle Benefit [2]
Air Conditioner Diagnostics	$50	none	$50		
Repair Duct Leakage	$200.00	$50.00	$192.50	$1489	$1011
Correct Low Airflow	$50.00	$15.00	$58.75	$204	$52
Repair Overcharge	$100.00	$25.00	$98.75	$256	$135
Repair Undercharge	$200.00	$50.00	$173.75	$235	($6)
Adjust Fan Off Time	$50.00	$15.00	$45.00	$264	$121
Adjust Fan Off Temp	$15.00	$0.00	$20.00	$37	($15)
Reset Anticipator	$5.00	$0.00	$10.00	$38	$0
Correct Underfired Furnace	$50.00	$15.00	$45.00	$33	($43)
Correct CO	$100.00	$25.00	$98.75	$0	($115)

1. Participant net benefit does not include effect of the rebate.
2. Net benefit is gross benefit minus cost. Utility lifecycle benefit is based on reductions at on-peak and mid-peak. The analysis predicts peak reduction at super-peak (coincident peak) which is not included in this benefit calculation.

The net lifecycle benefit would change substantially with climate and use patterns. In this case the kWh saved was substantially leveraged because these houses were high energy users.

Changes that shift the costs from the utility to the participant will rapidly impact the net benefit to PG&E.

IV. Conclusions

The PG&E Appliance Doctor Pilot Project has identified a significant source of untapped electrical and gas savings. This potential saving resides in bringing the existing cooling and heating equipment up to its designed efficiency. Field testing has proven that these repairs are economically feasible. In addition these repairs have the potential to improve customer satisfaction.

A 24.4% cooling energy savings and 12% heating savings can be accomplished by a program that diagnoses and repairs duct leakage, airflow, and overcharge on residential central air conditioners similar to those in the study.

Information developed in this project has implications for all residential air conditioners and gas forced air furnaces in PG&E's service territory. It has special significance for high bill complaint customers (ECI's) systemwide.

High Bill Complaints

In all cases the cooling energy use could be lowered by 10% to 30% without extreme effort. The heating savings on the same units averaged 16%. In the residences studied, high bill complaints were attributable to significant problems with heating and cooling equipment, the distribution system, and the building shell.

Existing Infrastructure

The Fresno pilot showed that the existing hvac contractor infrastructure was not able to identify and solve the problems that led to high bill complaints. This can be attributed to a business environment that concentrates on low first cost and lowest bid. This business atmosphere results in poor installations and inadequate time available to diagnose and repair the extreme problems that exist.

V. Recommendations

The Fresno pilot project has demonstrated that substantial energy savings is available by repairing existing heating and cooling systems. Along with these savings comes an improved customer relationship and a substantive response to high bill complaints. For these reasons the following actions are recommended.

Program Implementation

1) Implement the diagnosis and repair program developed in the pilot as a service to high use air conditioning customers. Include in this program repairing duct leakage, increasing airflow, and correcting overcharge.
2) For gas forced air furnaces, implement a system to lower the fan off temperature, adjust the anticipator, and check for carbon monoxide in the flue.
3) Provide sufficient economic incentive to motivate the hvac contractor to follow the system, spending the time necessary to perform the tasks properly.
4) Provide training on the system to insure that the contractor's technicians can perform the tasks.
5) Utilize reporting, inspection, feedback, and control to insure that the system is being followed.

Evaluation and Future Development

1) Continue the submetering analysis of the pilot homes into the summer of 1991 to confirm the peak demand and summer use savings.
2) Complete a long term pre-/post-repair utility bill analysis on the homes in the pilot project and on the production program. Only through such analysis can the true effect of programs be determined.
3) Investigate the actual savings potential from adding fan run time at the end of the air conditioner cycle. Quantify the trade-off between interior humidity and sensible heat removal for climates in PG&E's service territory.
4) Determine what percentage of the residential air conditioner customer base can be serviced cost effectively with the diagnosis and repair program.

New and Replacement Residential Air Conditioner Efficiency Programs

While efficiency improvement can result in reductions in coincident peak, the most certain reductions would come from installation of higher efficiency air conditioners.

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If incentives are considered for new or replacement high efficiency air conditioner installations, these installations should be held to strict criteria, including:

1) The measured airflow must be between 5% below and 15% above the manufacturer's specification.
2) The installed Energy Efficiency Ratio must be tested on site and be within 5% of the manufacturer's specification.
3) The inside coil and filter must be accessible for cleaning.
4) For new construction, the size of the unit must not exceed the size specified from Manual J calculations.
5) For replacement units, the size of the new unit must be the same or less than that of the existing unit.
6) For new construction, the ductwork must be sealed with mastic at every joint, the duct leakage tested, and known to be less than 150 cfm at 50 pa. house pressure.

Appendix A

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Appendix B

Distribution Duct Leakage

Distribution Duct Leakage

TEST METHODOLOGY

House and duct leakage testing was conducted by sealing all ac/furnace registers with plastic except the largest return register. The filter was removed from the open register and the house was pressurized to 50 pascals using a Minneapolis Blower Door. At that house pressure the following measurements were made:

1) A single flow pressure was taken at the blower door. This value was used to compute the airflow into the house using a single point method (Energy Conservatory, 1988).
2) A commercial flow hood measured the airflow through the open register.
3) The pressure difference between the duct at a middle supply register and outside was recorded.

The two most common means of duct leakage measurement are the subtraction and flow hood methods. Both were tested in the Auburn Heat Pump Pilot (Proctor et al., 1990). The subtraction method is based on taking two whole house leakage tests, one with the registers uncovered and one with them covered. The difference in flow between the two tests is the duct leakage.

The subtraction method is more time consuming than the flow hood method described above. It cannot accurately measure the leakage on duct work that is fairly tight because even small percentage errors in measuring the overall house leakage represent a large error in the smaller duct leakage number.

The flow hood method, on the other hand, cannot successfully maintain a pressure near 50 pa. in the duct work. This is due to flow restrictions at the register and through the distribution system. Leakier ductwork will result in lower duct pressures.

The mid-register pressure measurement was tested as a means of correcting the flow hood leakage measurements to approximate what they would be at 50 pa.duct pressure. This estimate was accomplished by the formula:

$$DL_{50} = DL_p \times \left(\frac{50}{p}\right)^{.65}$$

<u>Where</u>

DL_{50} = Duct Leakage at 50 pa. Duct Pressure

DL_p = Duct Leakage at pressure p (in pa.)

Using the mid-register flow adjustment appeared to improve the results of the flow hood test. Direct comparison to the subtraction method should be undertaken. The mid-register pressure should be considered as another measure of duct leakage. When the ducts are leaky the mid-register pressure is low. The comparison between mid-register pressure and flow hood measured duct leakage corrected to 50 pa. duct pressure is shown in Figure 13.

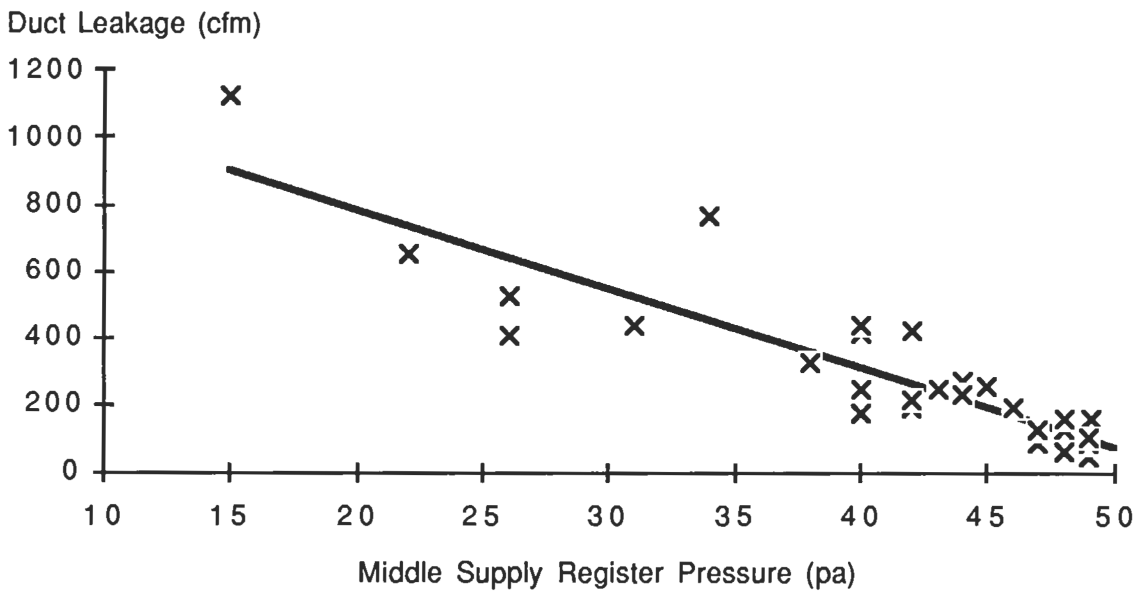

Figure 13. Duct Leakage Test Correlation
Middle Supply Register Pressure vs. Flow Hood Test

For these units, the mid-register pressure was a good predictor of the corrected results (R^2 = .757). The coefficient of determination (R^2) of the for the raw flow hood data to the mid-register pressure was .543.

The duct leakage reported in the remainder of this appendix is based on the raw measured flow from the flow hood test without the correction to 50 pa. pressure explained above. It is assumed that the lower pressures are more representative of actual duct pressures for leaky ducts.

CALCULATION METHODOLOGY

1.Added Infiltration with fan on due to Duct Leakage: from Palmiter (1990)

Q_{add} = Infiltration added by duct leakage
Q_{fan} = Air handler fan flow
F_s = Supply leak cfm ÷ Q_{fan}
F_{max} = MAX(F_s,F_r)
Q_{nat} = Natural infiltration
F_r = Return leak cfm ÷ Q_{fan}
F_a = Q_{add} ÷ Q_{fan}
F_{min}= MIN(F_s,F_r)

Assumption:
Neutral level at .5 height

With the blower on, the additional infiltration due to the duct leaks (Q_{add}) is:

When $(F_{max}-F_{min}) \times Q_{fan} \leq 2\ Q_{nat}$
$$Q_{add} = [\ .5 \times (F_{max} - F_{min}) + (1-F_{max}) \times F_{min}\ ] \times Q_{fan}$$

When $(F_{max}-F_{min}) \times Q_{fan} \geq 2\ Q_{nat}$
$$Q_{add} = [\ F_{max} - F_{min} + (1-F_{max}) \times F_{min} - (Q_{nat}/Q_{fan})\ ] \times Q_{fan}$$

Assumption used in this calculation for the study homes in which supply and return leak fractions were not measured:
Ratio of supply leak cfm to total leak cfm is same as average for intensive investigation units

2. Average Added Infiltration in Cooling Season due to Duct Leakage:

Assumptions:
The blower runs during 29.9% of the cooling hours. Based on submetered use and 358 hours in submetered period with outside temperature > 80°F

Percent of infiltration due to ducts when fan is off =
CFM50 duct leakage ÷ CFM50 total house leakage
(this is low due to positioning of duct leaks high and low in the house)

The average percent infiltration due to duct leaks =
$$.299 \times Q_{add} \div Q_{nat} + .701 \times \text{duct CFM50} \div \text{house CFM50}$$

3. Cooling Load due to Duct Leakage: from Palmiter (1990) (return leaks from attic added)

ΔT_{ac} = Temperature drop through air conditioner
ΔT_h = Inside to outside temperature differential
ΔT_a = Attic to outside temperature differential
F_{ra} = Return leak from attic cfm $\div$ Q_{fan}
E_{ac} = Actual capacity of air conditioner (btuh)
E_a = Cooling load due to duct leakage (btuh)
D_l = Distribution inefficiency due to leaks (%) = $E_a \div E_{ac}$

Assumptions:
$\Delta T_a = 20°F$ $\quad$ $F_{ra} = .5 \times F_r$
Other air handler return leaks are at outdoor temperature

Distribution loss due to duct leaks:

$$D_l = F_a \times (\Delta T_h \div \Delta T_{ac}) + F_s + F_{ra} \times (\Delta T_a \div \Delta T_{ac}) \times (1-F_s)$$

4. Heat Loss due to Duct Leakage: from Palmiter (1990)

ΔT_f = Temperature rise through furnace
ΔT_h = Inside to outside temperature differential
E_f = Actual output of furnace (btuh)
E_a = Heat loss due to duct leakage (btuh)
D_l = Distribution inefficiency due to leaks (%) = $E_a \div E_f$

Assumptions:
Air handler return leaks are at outdoor temperature
Initial furnace airflow = 95% of air conditioning flow
Average ΔT_h in heating period = 22°F
ΔT_f = measured ΔT_f at 5 minutes into cycle

The distribution loss due to duct leaks $D_l = F_a \times (\Delta T_h \div \Delta T_f) + F_s$

INTENSIVE DUCT LEAKAGE INVESTIGATION

Five of the last units were tested more intensively for duct leakage. These units were picked to represent the work of the technicians after the initial learning curve had begun to flatten out. In these units the flow hood test was run for total, return only, and supply only duct leakage. For the return and supply tests the supply system was isolated from the return by a plastic barrier at the furnace blower.

The supply and return leak fractions (leakage/total fan flow) are necessary for calculating the infiltration effect and energy loss due to duct leakage. The added infiltration in cooling from duct leakage in these five houses is shown in Table L.

Table L. Infiltration Effect of Duct Leakage in Cooling Mode (five sites)

House Identification	Blower Off	Blower On	Cooling Hours
AVERAGE	16.88%	63.20%	30.73%
10	12%	57%	26%
11	18%	66%	32%
12	25%	70%	38%
14	14%	60%	28%
15	16%	64%	30%

While the infiltration effect is important, it is not the largest energy loss attributable to duct leakage. For these units the largest energy loss in cooling was due to leakage of supply air cooled below inside temperature leaking to outside. The breakdown of energy loss due to duct leakage is reported in Table M.

Table M. Duct Loss Breakdown in Cooling Mode (five sites)

House Identification	Loss due to Additional Infiltration	Loss due to Return Leak in Hot Attic	Loss due to Supply Leak of Cooled Air	Total Loss due to Duct Leaks
AVERAGE	6.85%	9.07%	13.10%	29.02%
10	9.26%	9.73%	10.52%	29.50%
11	5.61%	9.92%	11.52%	27.05%
12	7.11%	7.80%	25.18%	40.09%
14	8.93%	10.36%	9.11%	28.40%
15	3.34%	7.55%	9.19%	20.09%

The average heating loss due to duct leaks in these five houses was 18.7%

Project technicians were able to approach the sealing goals on these five units; the results are shown in Table N.

Table N. Duct Sealing Results (five sites)				
House Identification	**Initial Duct Leakage (cfm)**	**Return Leakage (% of Total)**	**Final Duct Leakage (cfm)**	**Duct Leakage Sealed**
AVERAGE	431	62.42%	170	57.68%
10	380	65.79%	225	40.79%
11	596	63.93%	155	73.99%
12	515	49.51%	152	70.49%
14	342	67.25%	125	63.45%
15	320	65.63%	193	39.69%

After the initial learning period, technicians were able to seal almost 60% of the measured duct leakage. In a number of instances the location of the duct leak could be determined, however that location was inaccessible to repair. On House #10 the ducts between floors, in walls and in the crawl space were inaccessible. The sealing accomplished in the attic and on the roof accounted for a 40% reduction in duct leakage. Most of that sealing took place on the return system.

On House #15 the supply ducts were all in an inaccessible crawlspace. Sealing behind the supply registers at the junction between the boot and floor as well as sealing the return in the attic resulted in a 40% duct leakage reduction.

DUCT LEAKAGE RESULTS

The duct leakage results for all 15 houses is reported in Table O.

A.C. Number ID	AC CFM Delivery	House Size sq.ft.	AC Size tons	Initial Duct Leakage	Final Duct Leakage	House Leakage at 50 pa.	ACH Nat. LBL	DUCT % OF TOTAL INFILTRATION Blower off	Blower on	Cooling Hours	Loss due to Duct Leaks %
AVERAGE	***1131***	***1578***	***3.30***	***317***	***143***	***3385***	***0.68***	***11%***	***51%***	***23%***	***25%***
1	740	1680	2.58	355	236	3628	0.65	10%	49%	21%	32%
2	1148	1640	2.93	126	44	1782	0.26	7%	51%	20%	10%
3	1796	1102	3.17	385	58	3628	0.99	11%	54%	24%	19%
4	786	1450	3.17	170	80	5872	1.08	3%	27%	10%	16%
5	1265	2000	4.00	375	180	2601	0.35	14%	64%	29%	28%
6	832	1340	2.50	265	150	5169	1.16	5%	35%	14%	26%
7	1213	1300	2.92	190	82	3019	0.70	6%	42%	17%	14%
8	894	1488	2.92	270	155	1881	0.38	14%	61%	28%	26%
9	1012	1280	2.92	249	213	5115	1.20	5%	35%	14%	20%
10	1236	2548	5.17	380	225	3114	0.37	12%	57%	26%	30%
11	1867	2002	4.90	596	155	3330	0.50	18%	66%	32%	27%
12	1033	1170	3.00	515	152	2094	0.54	25%	70%	38%	40%
13	714	1400	2.50	213	101	5060	1.08	4%	31%	12%	32%
14	1230	1064	3.00	342	125	2485	0.70	14%	60%	28%	28%
15	1197	2202	3.75	320	193	2006	0.27	16%	64%	30%	20%

Appendix C

Air Conditioner Submetering

Air Conditioner Submetering

This Appendix elaborates on data collection, the hourly predictive model, thermostat control strategies, and the total savings analysis for the submetering of residential air conditioning units in the Fresno Appliance Doctor Pilot Project.

DATA COLLECTION

All fifteen sites were submetered with a Domestic Automation Company Type SM-DAC, Model TMC-101 kilowatt hour meter on the air conditioning circuit. This meter is capable of recording and storing the total kWh for various time increments and downloading the information to a laptop computer. The meter was programmed to record the total kWh use for every 15-minute period. All meters were downloaded four times by PG&E personnel. This data was analyzed for peak use, hourly use, occupant control strategy, and daily use.

THE PREDICTIVE MODEL

The predictive model was built in the following manner. The data was sorted and averaged over time to provide the proper resolution (ability to see cause/effect relationships). A linear regression correlating maximum air conditioner input to hourly outdoor temperature data was calculated. Similarly, another regression line describing the air conditioner use when the unit is cycling was computed. The intersection of these two lines is the onset of continuous operation and defines the temperature above which the air conditioner will run continuously.

Data Sorting and Smoothing

The data was sorted and periods that were unrepresentative because the air conditioner was starting its first cycle of the day or ending the last cycle were eliminated.

In order to preserve the information and also make the results understandable the 15-minute data was smoothed in two ways. The individual data points were summed for one-hour and averaged for two-hour increments. The one-hour summations were useful in determining the actual energy use of the air conditioner under continuous running. The two-hour averages provided a smoothed curve for periods when the unit was cycling and furnished some compensation for the lag time between outdoor temperature and cooling demand. The two-hour averaged data with start up peaks remaining for House #12 is shown in Figure 14.

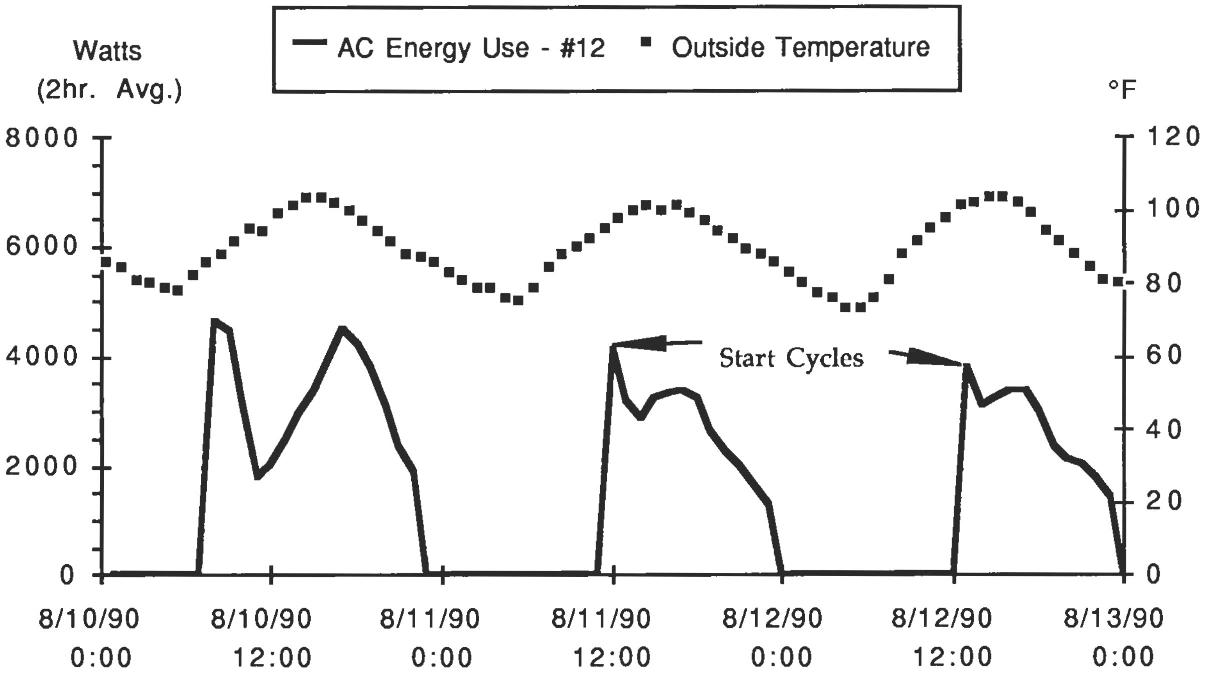

Figure 14. Two-Hour Averaged Submeter Data with Start up Peaks - AC #12

Maximum Air Conditioner Input Line

Continuous running creates the maximum sustained demand that an air conditioner will put on the utility system. Under these circumstances the input is dependent on the outside temperature. Continuous running conditions form a readily distinguishable limit line on the plot of use vs. outside temperature. This is shown in Figure 15.

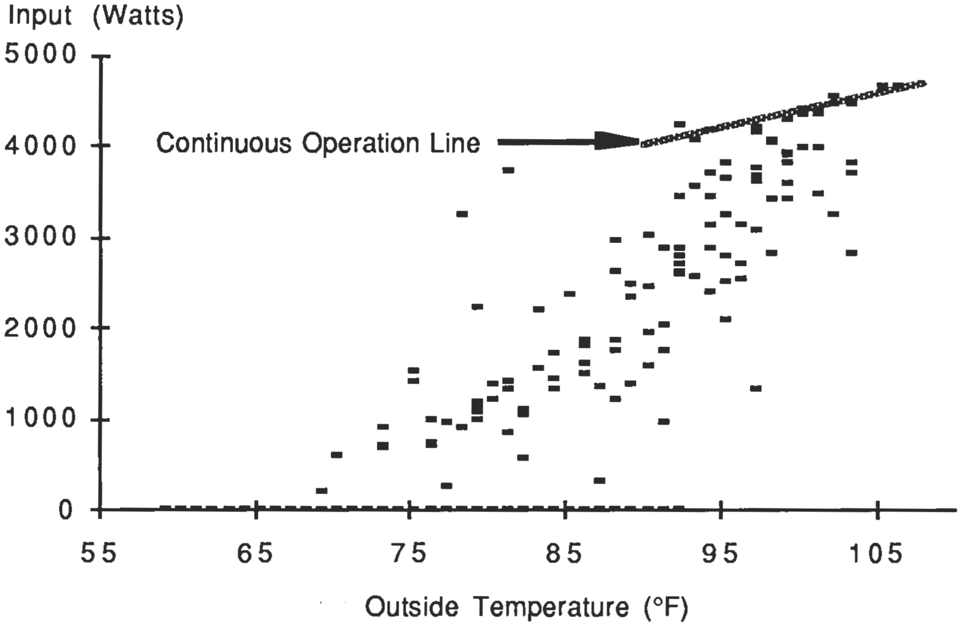

Figure 15. Air Conditioner Input Limit Line - 1-hour data #6

The data points that form the limit were selected from all of the data points; a linear regression of use against outside temperature shows how the outdoor temperature affects the maximum demand of the unit. This line is the maximum input line for the air conditioner. The R^2 of these regressions averaged .78.

Cycling Air Conditioner Input Line

The cycling energy input for any outdoor temperature was determined by screening and then regressing the two-hour average use data.

The two-hour average use data for cycles initiated by manual adjustment of the thermostat were screened out. These "Start Cycles" and "Stop Cycles" were excluded from the analysis since they do not represent normal cycling behavior but rather human initiated cycles. Periods of no use were also excluded from the analysis.

The remaining data points were sorted into two categories: use while the outdoor temperature was rising or steady, and use while the temperature was falling. These two data sets were regressed against temperature to determine their linear relationship to temperature.

The determination of a cycling input regression line is shown graphically in Figure 16.

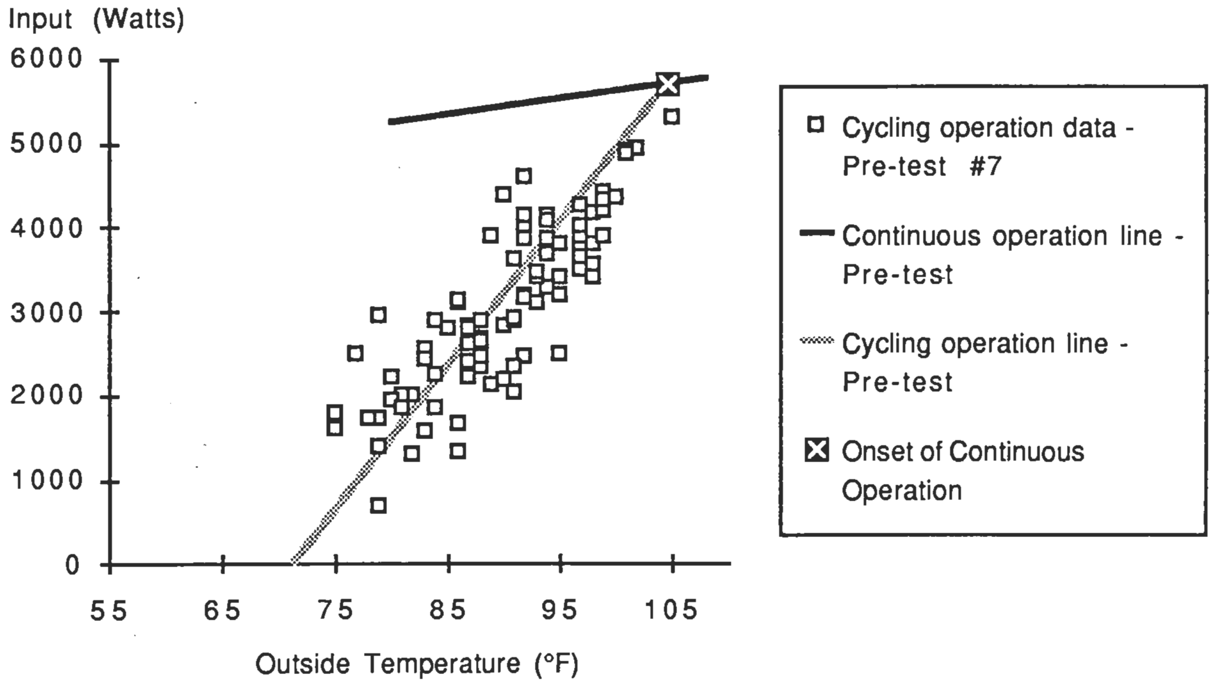

Figure 16. Air Conditioner Cycling Input Line and Onset of Continuous Operation - #7

Onset of Continuous Operation

The intersection of the regression lines for cycling and for continuous operation was labeled the Onset of Continuous Operation (OCO). The determination of OCO is shown in Figure 16.

When the temperature exceeds the OCO, the air conditioner is predicted to run continuously and the house temperature does not fall to the set point of the thermostat. This may result in occupant comfort complaints.

How the Predictive Model Operates

The model is based on the following assumptions:

1. Until it is sufficiently warm outside the air conditioner is off.

2. Energy use from these air conditioners rises linearly with temperature once the outside temperature exceeds the threshold.
3. At the temperature labeled "onset of continuous operation" the house cooling load is exactly matched with the output of the unit.
4. Above the OCO the unit runs continuously.
5. When running continuously the total input rises more slowly with outdoor temperature than during cycling.

If these assumptions are basically true and if there is adequate data to reduce the effect of random variations, the R^2 of the individual regressions will be high and therefore confidence in the predictions will be high. If the assumptions are incorrect or the data contains too much random variation for the size of the sample, the R^2 will be low and predictions will be impossible.

Predicting Peak Demand Reductions

In order to predict the effect of tested modifications on lowering peak demand, the predictive model described above was developed for both pre- and post-repair conditions. The outside temperature in Fresno at the time of the 1990 system peak was input to both models. The resulting one-hour demand was calculated for both conditions. The reduction in energy use from pre- to post-repair is the peak reduction for that house. This is illustrated in Figure 17.

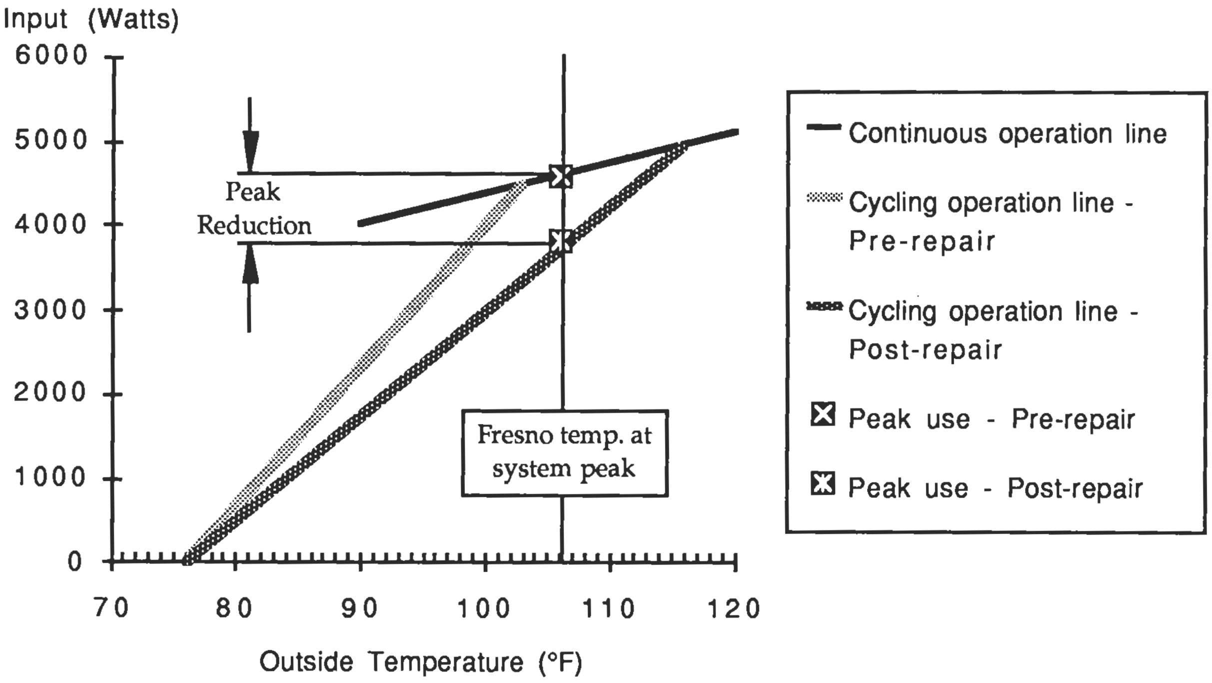

Figure 17. Peak Reduction Prediction by Regression Model - Example

When an efficiency improvement occurs, the slope of the cycling operation line is reduced. This simply means that less input power is needed to maintain the house at the same temperature. For certain modifications the continuous operation line will also be changed. For example adding charge will raise the continuous operation line, while removing charge will lower it.

For the example in Figure 17, reducing the slope of the cycling operation line has the following effect.

1. The onset of continuous operation is raised to a higher temperature.
2. Since the OCO temperature is now higher than the temperature at system peak, continuous operation is no longer necessary; the use at peak temperature now lies on the post-repair cycling line.
3. In the post-repair condition, at system peak temperature the air conditioner cycles with an hourly average input of 3800 watts.
4. In the pre-repair condition, at system peak temperature the air conditioner was running continuously with an input of 4600 watts.
5. This air conditioner's contribution to peak demand has now fallen by 800 watts, (4600 - 3800).
6. The house is now cooled to the thermostat set point thus increasing customer comfort.

The regression model will not only determine changes in the cycling operation line (efficiency changes), but also shifts in the continuous operation line. It calculates the effect of this shift on peak energy use. The most common example of a repair that will cause a shift in the continuous operation line is withdrawing excess charge from an overcharged system. This repair lowers the continuous operation usage and therefore reduces the peak use at temperatures hotter than the OCO. (It would also improve the efficiency of the unit and reduce the cycling slope).

THERMOSTAT CONTROL STRATEGIES

When the air conditioner is controlled by a constant thermostat setting in the range 75°F to 85 °F, a large percentage of the cooling hours are characterized by the unit cycling on and off.

While cycling operation is usually controlled by the thermostat, continuous operation is usually due to human intervention. When an occupant moves the thermostat to a lower setting the air conditioner runs continuously for a significant period of time. This is easily discernable in the data. If the occupant frequently adjusts the thermostat, a large percentage of the operating hours will show continuous operation rather than cycling operation. A similar pattern could be produced by a severely undersized unit.

The percentage of cooling hours exhibiting cycling is a good measure of control manipulation by occupants. The percentage of cycling hours was determined by counting the hours of non-continuous operation, excluding start-up and shutdown cycles, and dividing the result by the total hours of operation.

If the unit cycles during more than 90% of its run hours, the predominant control mechanism is a single set point for most of the day. If the percentage is less than 80%, manual resetting of the thermostat is a significant control mechanism. Figure 18 shows cycling percentages for the air conditioners in this study.

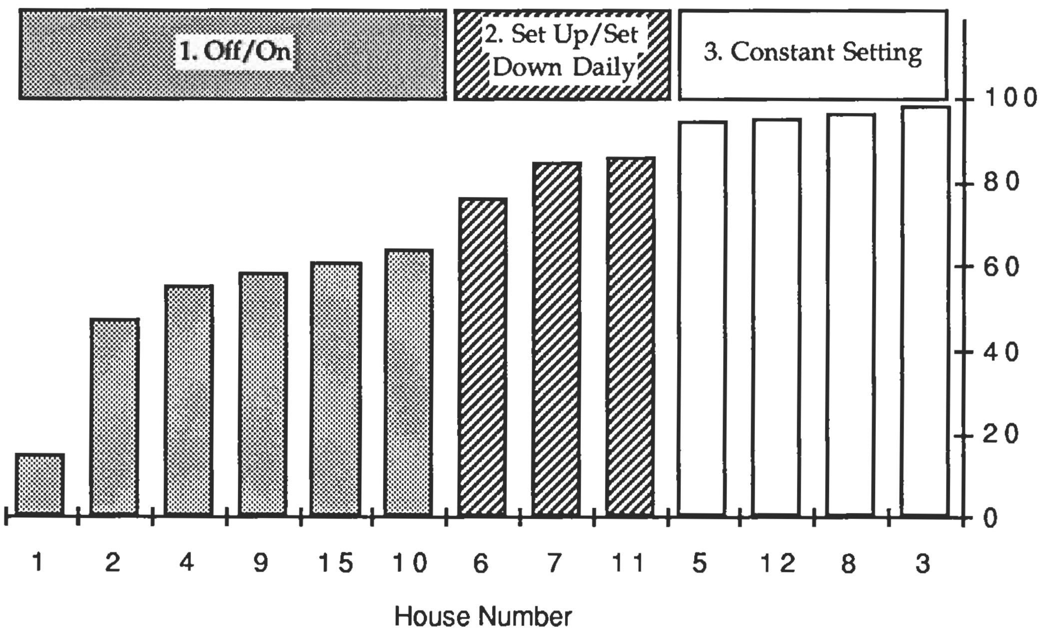

Figure 18. Thermostat Control Strategies

The occupants of the test houses utilized a variety of thermostat control strategies:

1. Off/on control - manually switching the thermostat on when the occupant wants it cooler and off when s/he considers it cool enough. This is accomplished with the off-cool switch on the thermostat or by adjusting the set point of the thermostat up/down. The extreme case of this type of control is House #1 where the occupant kept the thermostat set at 70°F and turned the switch on in the morning and off at night.

This behavior makes modifications to the system difficult to analyze since use is not necessarily related to outside temperature.

2. Daily set up/set down control - a consistent pattern of setting the thermostat up in the evening and down at some time during the day, with only occasional minor adjustments of the thermostat. The most reliable application of this procedure was by a programmable digital thermostat in House #11. The occupants did not override this control.

3. Constant temperature setting control - setting the thermostat at one temperature and nearly always leaving it untouched. The occupants of Houses #5 and #12 used night resets of less than 5°F and otherwise left the settings alone. They minimized continuous operation of the air conditioner.

For on/off or set up/set down control patterns the unit may operate continuously at any temperature. These control patterns impact the model by lowering the onset of continuous operation (OCO).

OVERALL SAVINGS ANALYSIS

The overall savings analysis was accomplished by creating a linear model of daily air conditioning use (AC use) vs. outdoor temperature for each home. The model was developed from data collected before and after repairs were conducted. Standardized weather conditions were applied to both the pre- and post- versions of the model. The reduction in energy use from pre- to post-repair was the total savings for that house.

Energy Use Model - Daily Use vs. Average Outside Temperature

The analysis started with the assumption that cooling energy use was linearly related to outside temperature and could be modeled by the equation:

$$\text{for } T_{avg} > T_{bal}, \qquad E = s \times (T_{avg} - T_{bal})$$

$$\text{for } T_{avg} \leq T_{bal}, \qquad E = 0$$

Where

- E = the energy used in a day with an average outdoor temperature of T_{avg}
- s = the slope (a constant), kilowatt hours used for each °F that T_{avg} exceeds T_{bal}
- T_{avg} = the average temperature for that 24 hours

T_{bal} = the derived balance temperature - sometimes interpreted as the average daily temperature below which cooling energy is no longer used

The 15-minute submeter data was totaled every day. Days were eliminated for any one of the following reasons:

1. No usage during that day.
2. Abnormal use because of testing conducted as part of this program.
3. Occupant vacations or other reported atypical behavior.

Hourly temperatures from the Fresno airport weather station were averaged to give the T_{avg} for each day. A least squares regression was performed to obtain the best straight line fit of the usage to the temperature data. This regression established both the slope, s, and the balance temperature, T_{bal}. The data and regression lines for both the pre- and post-repair conditions for one house are shown in Figure 19.

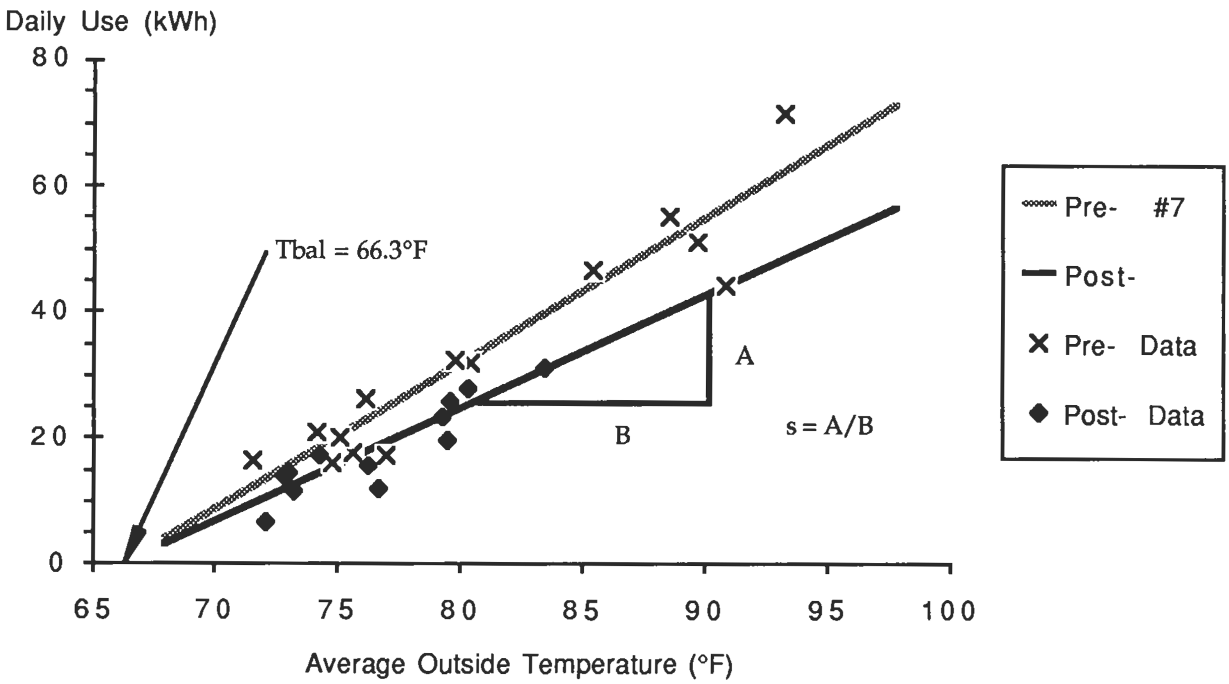

Figure 19. Linear Regression of Daily AC Use vs. Average Temperature - AC #7

The adequacy of each regression was judged by the R^2 (and the standard deviation of the response variable about the regression line). The R^2 measures the fraction of the variation in daily kWh that is linearly accounted for by changes in the outdoor temperature. If all the variation in use is accounted for by changes in temperature, R^2 would be 1.00. Values less than 1.00 indicate that other factors, possibly including occupant adjustments to the thermostat, may be responsible for some of the changes in daily use. The daily use analysis R^2's are reported in Table P.

Table P. Daily Use Analysis Regression Data

AC Number ID	Pre- R^2	Pre- data points (days)	Post- R^2	Post- data points (days)
1	0.846	9	0.202	9
2	0.958	6	0.054	6
3	0.959	15	0.74	13
4	0.704	6	0.375	13
5	0.934	17	0.863	18
6	0.869	7	0.815	8
7	0.903	14	0.826	13
8	0.851	12	0.822	11
9	0.242	4	.012	9
10	0.791	26	0.548	15
11	0.925	17	0.834	12
12	0.828	23	0.717	14
15	0.739	9	0.793	6

Twelve houses had adequate predictable pre-repair use for the regression to be meaningful (R^2 is greater than .70). The occupant of House #9 used the air conditioning only sporadically and did not use it in a pattern clearly related to outdoor temperature. The average R^2 is .859 for the other twelve houses.

<u>Normalizing to Standard Weather</u>

The regression coefficients from the daily use analysis provide one measure of the actual savings accomplished on the pilot houses. To provide a meaningful comparison between pre- and post-repair conditions the results must be applied to standard weather conditions.

Average temperatures for a typical summer (June through September) were obtained by using data from the Fresno TMY (Typical Meteorological Year). The resulting daily temperatures were binned in 1 °F increments. The energy use, E, was calculated for all pre- and post- regressions with an R^2 greater than .70. The use for all the bins was summed to obtain a weather normalized estimate of the energy before and after the work was done.

Total Savings

The change in weather normalized use between pre- and post- periods is the total energy savings attributed to the modifications. The percentage savings is given by the formula:

$$\text{Percentage Savings} = \frac{\sum E_{pre-} - \sum E_{post-}}{\sum E_{pre-}}$$

Post-test weather conditions did not include the extreme high temperatures that occurred during the pre-repair period. This results in fewer days with the air conditioner running and less reliability in the regressions. For these reasons, four houses failed to pass the R^2 greater than .70 criteria for the post-repair period. The R^2 for the remaining eight houses was .801. The submeters remain in place. Data from high temperature days in the summer of 1991 should produce adequate data to improve the regression fit of a follow-up analysis.

Appendix D

Forced Air Signature Test

Forced Air Signature Test

This appendix provides background and methodological details on the signature test used in the PG&E Appliance Doctor Pilot Project. It also contains additional detail on the furnace defining equations and the investigation into adding sensible cooling to the end of the air conditioner cycle.

OVERVIEW

Furnaces and air conditioners at five homes were tested utilizing the forced air signature test (FAST). The signature test provided a rapid and reliable evaluation tool to determine actual in-place furnace efficiency. This tool produced efficiency of the unit for entire cycles, not just steady-state conditions.

The units were tested for cycles of 5, 10, and 20 minutes. During each cycle the output was measured at 15-second intervals and the (on/off) condition of the gas valve and blower were monitored. The tests were run both before and after modifications to the unit, and permitted a mathematical derivation of actual in-place efficiency for different run times. The savings from modifications and repairs was then calculated.

BACKGROUND

Testing the steady-state efficiency (SSE) of forced air furnaces is a commonly employed technique which computes the energy leaving the building in the stack gasses. It reports the result as a percentage of the furnace input. When this technique is applied to a furnace that has run over 20 minutes it is a good measure of stack loss at steady-state conditions. The problem with the SSE is that it measures only the stack loss, merely one of the losses. The lack of an adequate test for field measurement of seasonal furnace efficiency has lead to the use of a number of "fudge factors" being added to the steady-state efficiency test to create an estimated seasonal efficiency. An example of this technique is the RCS audit. In order to accurately determine both the potential energy savings and the actual energy savings, a more inclusive measure is needed.

This pilot project utilized the field test procedure described below to determine furnace cycling efficiency. The test procedure has been used successfully in several projects and has evolved with each use:

1. In 1979 Jay McGrew calculated the actual output of gas forced air furnaces by measuring airflow and temperature rise. This data was coupled with input measurements to determine the true efficiency of a furnace as it was installed in a house. This method derived the actual efficiency (output to the delivery system/input to the furnace) for a particular cycle length.
2. The Solar Energy Research Institute (Subbaro, 1986; Frey, 1985) used the technique in 1985 to determine the efficiency of a furnace before and after modifications. The results of this study are discussed in detail in Proctor and Foster (1986).
3. In the 1987 Sun Power Accelerated Monitoring program (deKieffer & Proctor, 1988) FAST was employed on a 20-house sample of furnaces utilizing standardized procedures. In that study FAST proved to be a reliable and repeatable test. It also proved itself as a rapid technique of measuring the efficiency changes and savings associated with furnace modifications that affect seasonal furnace efficiency.
4. A test of furnace efficiency modifications was conducted in 1989 on five houses using SERI's Short-Term Energy Monitoring (STEM) procedure. (Balcomb, 1990). FAST was conducted before and after modifications as part of the testing procedure. The FAST results were combined with the STEM results to obtain pre-/post-modification distribution efficiency. In addition, for the first time the test was performed sequentially while varying individual furnace parameters. This tested the effect of those particular parameters on performance. Aided by a three-dimensional computer graphics programs, linear equations were derived that describe furnace performance under a wide range of conditions. Predictive equations from the 1989 test were combined with field parameter test reports on 1000 furnaces, permitting the determination of savings potential and achieved savings for each furnace. This data was used to analyze the performance of different agencies and personnel charged with delivering a furnace efficiency program to low-income individuals. These tests provided verification against other evaluation methods.
5. In a 1990 test for Wisconsin Gas Company (Vick & Jablonski, 1990), FAST was used to measure the effect of a furnace efficiency improvement pilot program on 13 furnaces in commercial buildings. This was the first application of the procedure on commercial roof-top furnaces. Use of the procedure allowed immediate analysis of the program's effectiveness in obtaining the desired savings.

6. In a 1990 pilot project for Pacific Gas and Electric Company, the signature test was successfully used to test the on site efficiency of heat pumps. (Proctor et al.)

FURNACE SIGNATURE TEST

The elements of FAST are:

1. Tight control of the testing procedures to achieve repeatable and reliable results.
2. Measurement of the airflow through the furnace.
3. Measurement of the rise in air temperature at 15-second intervals as it travels from the return air plenum through the furnace to the delivery air system.
4. Measurement of furnace input.
5. Calculation of the cumulative furnace efficiency.
6. Derivation of the defining equations for each furnace to predict the furnace's performance under a variety of conditions.

Test Control

Past experience and the results of this pilot dictate 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 perform the following tasks.

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 stack temperature and stack O^2 at the proper times.
5. Using prompted inputs, record the test conditions and technician measured results in one file for later analysis.

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.

The McGrew study used a hot wire anemometer to measure airflow. In this method, a probe is traversed across the airstream. The probe contains a wire which is heated by an electric circuit. When the airflow increases, the current through the wire increases. This change in current is used to measure the airflow.

The 1985 SERI study installed an electric resistance heater in the delivery plenum to input a known amount of energy into the airstream. They then used the temperature rise method detailed below to measure the total CFM (cubic feet per minute) through the furnace. The same method was employed in the 1990 PG&E heat pump study using existing electric resistance back-up heaters.

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 temperature rise. In the furnace signature test, steady-state efficiency and temperature rise (S.S. Eff. and S.S. Temp.Rise) are measured after 20 minutes of continuous operation. The airflow, in cubic feet per minute (CFM), is calculated as follows:

For Electric Input $$\text{CFM} = \frac{3.16 \text{ X Input Watts}}{\text{S.S. Temp.Rise in °F}}$$

For Gas Input $$\text{CFM} = \frac{.926 \text{ X Input Btu/hr X S. S. Eff.}}{\text{S.S. Temp.Rise in °F}}$$

The conversion factors are derived as follows:

A 0.018 Btu/°F ft^3 (Heat capacity of air)

B 3.414 Btu/Watt hour

C 60 minutes/hour

$$\frac{B}{A*C} = 3.16 \qquad \frac{1}{A*C} = .926$$

Measurement of S. S. Eff., S.S. Temp. Rise, and Input Btu/hr. are described below.

MEASUREMENT OF STEADY-STATE EFFICIENCY

When testing a furnace for CFM, the input of energy into the airstream must be determined. For a resistance electric furnace, this requires only a measurement of the watts input to the heater. For a gas furnace however, the derivation is not so straightforward. The input into the airstream is not equal to the input rate of the furnace, nor is it constant over time.

Determining the input to the airstream is accomplished 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 test methodology. This determines steady-state efficiency as a percentage of the furnace input rate.

Measurement of Temperature Rise

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.

Measurement of Furnace Input

The furnace input is measured by running the furnace with all other gas appliances turned off. The gas meter dial is clocked three times and the average time for one revolution of the one-quarter, one-half, or two-foot dial is recorded. The input is calculated by the formula:

$$\text{Input (Btu/hr)} = \frac{\text{Dial ft}^3 \text{ per revolution } \mathbf{X} \text{ Btu per ft}^3 \mathbf{ X} \text{ 3600}}{\text{Avg. seconds per revolution}}$$

<u>Where</u>

3600 = seconds per hour

and Btu per ft^3 is obtained from the local gas company

Measurement of the input rate of the furnace is necessary only if the furnace is being used to determine the airflow rate for another appliance, such as an air conditioner. The input rate drops out of the final equation when signature testing the furnace.

When the electrical input is used in the analysis, it is measured with the house meter.

Calculation of Cumulative Efficiency

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

When the blower is on $\quad \text{Output} = \Delta T_{avg} \text{ X } 1.08 \text{ X CFM}$

When the blower is off $\quad \text{Output} = 0$

<u>Where</u>

ΔT_{avg} = the average temperature rise between the delivery and return temperatures for the previous 15 seconds

1.08 = A*C the reciprocal of .926 used in the CFM calculation

A = 0.018 Btu/°F ft^3 (Heat capacity of air)

C = 60 minutes/hour

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

When the gas is on $\quad \text{Input} = \dfrac{\text{elapsed time (sec.) X Input (Btu/hr)}}{\text{3600 sec. per hr.}}$

When the gas is off $\quad \text{Input} = 0$

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

$$\text{Cumulative Efficiency at time } t_n = \frac{\sum_0^n \text{Output}}{\sum_0^n \text{Input}}$$

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 is shown in Figure 20.

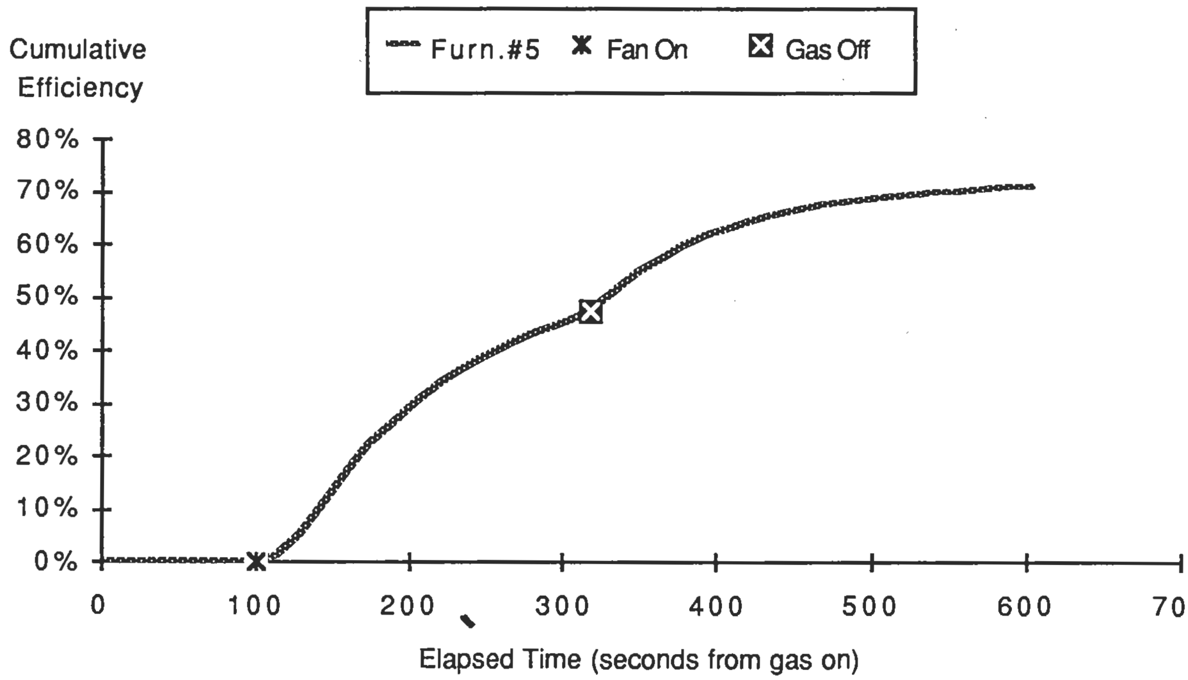

Figure 20. Furnace Signature 5-Minute Cycle Furnace #5

Derivation of Defining Equations

Defining equations are derived for each furnace under each test condition (pre-/post-) 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 then used in a regression analysis that produces the defining equation for each furnace test condition.

The cycling efficiency (cumulative efficiency at fan off) is essentially a linear function of the fan off temperature for each cycle length (shown in Figure 21).

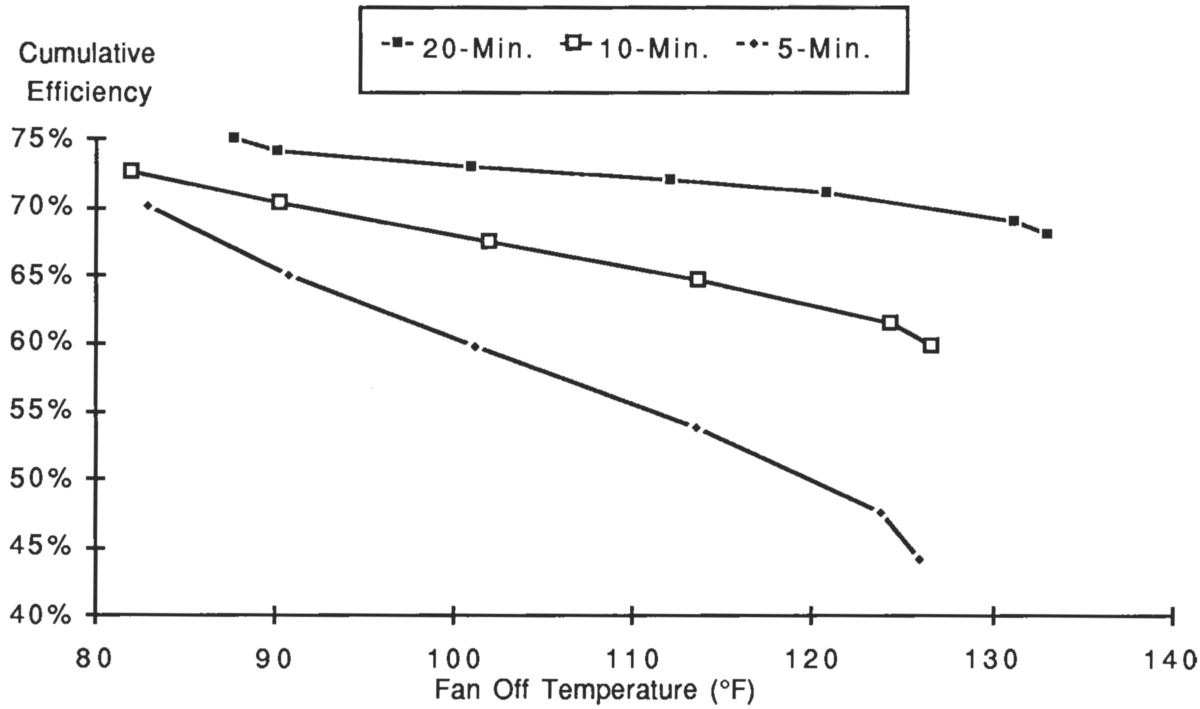

Figure 21. Fan Off and Cycle Length Effect on Efficiency - Furnace #5

It has been determined in previous studies (deKieffer, 1990; Vick and Jablonski, 1990) that these series of curves can be represented by a single equation of the form:

$$\text{Cycling Eff.} = \alpha + \beta \times \frac{(T_{off} - \gamma)}{t_{cycle}}$$

<u>Where</u>

α	=	the intercept of the regression, this approaches the S.S. Eff.
β	=	the slope (a constant), efficiency decrease due to changes in fan off temperature 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

The calculated efficiencies from the three cycle tests (5-minute, 10-minute, and 20-minute) are selected for fan off temperatures in 10°F increments from the delivery temperature at gas off to 80°F. 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

The defining equations for the five tested furnaces are reported in Table Q.

Table Q. Defining Equations for Furnace Cycling Efficiency

$$\text{Cycling Eff.} = \alpha + \beta \times \frac{(T_{off} - \gamma)}{t_{cycle}}$$

Identification	α	β	γ
Furnace #1 pre-	.7573	-1.551	76
Furnace #2 pre-	.8089	-1.869	87
Furnace #2 post-	.8061	-2.477	92
Furnace #4 pre-	.7936	-2.131	80
Furnace #4 post-	.7711	-2.816	96
Furnace #5 pre-	.7729	-1.115	62
Furnace #5 post-	.7745	-1.760	69
Furnace #14 pre-	.6299	-3.145	97
Furnace #14 post-	.7574	-2.313	94

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. In this study the actual fan off temperatures were used and t_{cycle} was fixed at 5 minutes. The actual cycle time for furnaces was measured in other studies (deKieffer and Proctor, 1988) and found to vary from over 20 minutes to less than 2 minutes, with an average around 4-1/2 minutes. The furnaces in Fresno are large for the climate and size of the houses, so they tend to have shorter cycles and lower efficiencies.

The savings is estimated by:

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

<u>Assumptions</u>

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 (McGrew, 1979) 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. 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. FAST tests are planned to determine the actual effect of various cycle off times.
6. 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 furnace cycle does not vary substantially except in very cold weather (deKieffer and Proctor, 1988)

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

The efficiency calculated in this report is based on the gas input. This excludes the electrical energy to run the fan. Basing the calculation on the total energy use, including fan energy, reduces the efficiency numbers for the entire cycle. It also limits the effective fan run time at the end of the cycle. Neither of these changes have a significant effect on the conclusions, since the run time at the end is actually determined by comfort considerations and the fan input is small compared to the gas input.

SENSIBLE COOLING FROM EXTENDED FAN RUN TIMES

The Forced Air Signature Test was used on the five air conditioners to determine the sensible cooling effect of running the inside fan after the compressor is shut off. The sensible capacity of each air conditioner was measured, the electrical input and sensible efficiency calculated.

Measurement of Sensible Capacity

The equivalent to measuring the output of a furnace is measuring the capacity of an air conditioner. Measuring the delivery and return dry-bulb temperatures and airflow establishes the sensible capacity of the air conditioner.

The dry-bulb temperature readings and airflow measurements were taken in exactly the same manner as in the furnace tests. The inside fan control was modified to allow the fan to run after the compressor had shut off.

Note that an air conditioner does more than cool indoor air. It also removes moisture from the air. This additional latent capacity is a significant part of the total capacity of the air conditioner.

Calculation of Electrical Input

The outdoor temperature during each cycle test was recorded. This temperature was used to calculate input to the unit utilizing the continuous running input equations derived in submetering analysis. The results were checked by clocking the air conditioner submeter.

Since the unit was tested with the fan running after the compressor was off, that input was determined by clocking the submeter.

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

When the compressor is on:

$$\text{Input} = \frac{\text{elapsed time (sec.) X Total AC Input (watts)}}{\text{3600 sec. per hr.}}$$

When the compressor is off:

$$\text{Input} = \frac{\text{elapsed time (sec.) X Inside Fan Input (watts)}}{\text{3600 sec. per hr.}}$$

The primary input measurement assumption is that the compressor on power input is effectively constant at its steady-state value. The Florida Solar Energy Center study (Khattar et al., 1987) showed this to be nearly true, with a higher initial inrush followed by a short period of consumption slightly below the steady-state value. The total input is closely approximated by the steady-state value multiplied by the time interval.

<u>Calculation of Sensible Efficiency</u>

The efficiency of an air conditioner is calculated as the energy efficiency ratio (EER). In this study the Sensible Cumulative EER was calculated as follows:

$$\text{Sensible Cumulative EER at time } t_n = \frac{\sum_0^n \text{Sensible Capacity}}{\sum_0^n \text{Input}}$$

The Sensible Cumulative EER (Sensible CEER) for three different run times is shown in Figure 22.

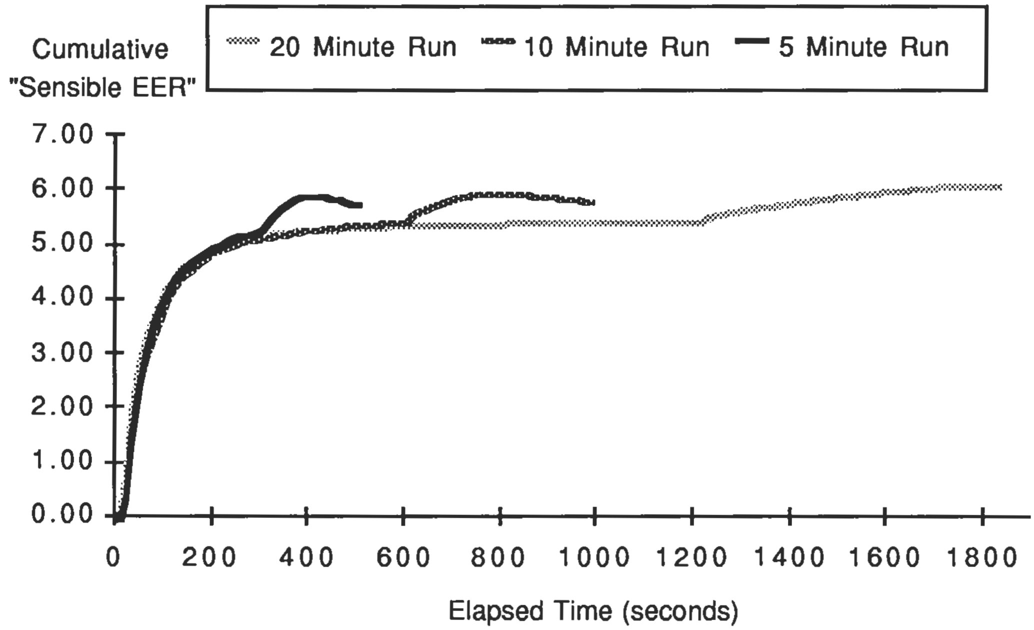

Figure 22. "Sensible Cumulative EER" - Air Conditioner #4

Potential Energy Savings from Continued Fan Run Time

The difference between the maximum sensible efficiency and the sensible efficiency at compressor off (normal control) is the maximum improvement in Sensible CEER. The potential savings from that improvement is calculated as:

$$\text{Savings} = \frac{\text{Max. Sensible CEER} - \text{Normal. Sensible CEER}}{\text{Max. Sensible CEER}}$$

Table R. shows the results of that calculation for each of the five air conditioners.

Table R. Potential Cooling Savings from Extended Fan Run Time			
Identification	**5-minute cycle**	**10-minute cycle**	**20-minute cycle**
Air Conditioner #1 pre-repair	17.7%	14.5%	13.2%
Air Conditioner #1 post-repair	11.8%	10.6%	9.8%
Air Conditioner #2 pre-repair	14.4%	15.3%	4.1%
Air Conditioner #2 post-repair	8.5%	3.9%	3.4%
Air Conditioner #4 pre-repair	10.9%	8.9%	10.7%
Air Conditioner #4 post-repair	4.1%	4.5%	2.0%
Air Conditioner #5 pre-repair	19.9%	16.8%	12.5%
Air Conditioner #5 post-repair	21.2%	18.9%	15.0%
Air Conditioner #14 pre-repair	13.3%	6.6%	4.0%
Air Conditioner #14 post-repair	8.8%	5.6%	3.4%

Appendix E

Savings Estimation Methodology

Savings Estimation Methodology

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The analysis in this report uses multiple methodologies in order to obtain the most accurate savings estimates for each item. Empirically based methodologies are preferred since they usually result in lower yet more accurate savings estimates than simple engineering calculations.

The steps of the analysis for an individual air conditioning measure are:

1) Estimate energy savings and change in continuous running input (CRI) for the retrofit measure. This is detailed for each item in this appendix.
2) Using the predictive models developed from the submetering analysis, estimate the peak reduction from that measure for each study home.
3) Calculate the average peak reduction for the study homes.
4) Utilize the savings estimate and average peak reduction, along with cost and lifetime data, to calculate benefits to the participant and utility, benefit cost ratios, and net lifetime benefit.

The additional steps for multiple measure analysis are:

1) Combine the savings and CRI for each measure in a manner that takes interactions into account. This takes the form: combined sav% = 1 - (1-sav$\%_1$) x (1-sav$\%_2$) x (1-sav$\%_3$) etc. For CRI the new continuous running input was calculated as: initial CRI x (1-reduction$\%_1$) x (1-reduction$\%_2$) x (1-reduction$\%_3$) or initial CRI x (1+increase$\%_1$) x (1+increase$\%_2$) x (1+increase$\%_3$).
2) Use the combined savings in the predictive models to estimate the peak reduction from these measures for each study home.
3) Calculate the average peak reduction for the study homes.
4) Repeat steps 1) through 3) for each multiple measure group.
5) Calculate a weighted (by % of occurrence) average energy savings and peak reduction for the whole program.
6) Utilize the combined savings estimate and average peak reduction, along with cost and lifetime data, to calculate benefits to the participant and utility, benefit cost ratios, and net lifetime benefit.

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Correct Air Flow

The savings for increasing airflow through the inside coil was analyzed in the following manner.

The instantaneous EER data for each unit before and after the airflow work was done was recorded. The savings due to the EER change was calculated and corrected for ambient temperature effect on EER. The resultant savings was the dependent variable in a least squares regression analysis utilizing Data Desk Professional software from Odessa Corporation.

The regression analysis and regression diagnostics are described in detail in the Data Desk Statistics Guide by Velleman, P. and Velleman, A. (1988).

The predictor variable used in the regression was the change in airflow as a percent of specified airflow. The results were:

airflow %	coefficient	1.489	standard error	.7815

This regression was a poor predictor, however: the R^2 was only .312.

A similar regression was performed for the airflow change vs. savings in the heat pump study (Proctor et al., 1990) that resulted in a substantially better R^2 (.897). The results of that regression were:

airflow %	coefficient	.854	standard error	.0965

The mean flow increase for the air conditioners initially below 375 CFM/ton was 16%. For this change in flow the above regression from the heat pump study yields .16 x .854 = 13.7% savings

Krafthefer et al. (1987) modeled the effect of dust accumulation on the energy use of heat pumps in both the heating and cooling mode. They concluded that after 15 years (the average age of air conditioners in the Fresno study was 17 years) the average operating cost savings was from 10% to 25% through the use of a high efficiency air cleaner. Cleaning the coil should achieve similar benefits.

Krafthefer also performed a laboratory test of COP change vs. airflow improvement from coil cleaning. That test showed a 14.7% savings from an airflow improvement of 30.4%. For a 16% change in airflow the corresponding savings (linear assumption) would be 7.7%.

Trane Company's test of an eight-year-old air conditioner showed a 20% improvement in efficiency by cleaning both coils and adjusting to proper refrigerant charge. (Trane Company, 1976)

Based on the Krafthefer laboratory tests the estimated cooling savings from coil cleaning is 7.7% for the units that had a low flow problem.

The CRI increases when the coil is cleaned. Krafthefer's model predicts a 5% to 7% increase in continuous running power after 3 to 5 years. His model seems to overestimate the effect of a dirty coil when compared to his lab tests and our field tests in the heat pump and Appliance Doctor studies.

House #5 had a significant increase in airflow (46% of designed airflow) and showed an increase in CRI of 16%. Based primarily on the field submetered data, the increase in CRI is estimated at 5% for an increase in flow of 16%.

The heating savings for the units with a low flow problem is estimated at 1.9%. This is based on a 1.2% savings for every 10% savings in airflow. It is derived from cycling (FAST) tests of furnaces while changing airflow. (deKieffer, 1990)

Repair Overcharge

Repairing overcharge is estimated to save 11.5% of the cooling energy use. This is based on the laboratory tests by Farzad and O'Neal (1988). The average overcharge of these units was measured at 10%. Their lab tests show the change in use from 10% overcharge to correct charge as 11.5% for an ambient temperature of 100°F and a 700-watt indoor fan.

The corresponding decrease in CRI is 1.2% according to their tests.

Repair Undercharge

Repairing a 20% undercharge is estimated to save 11.8% of the cooling energy use, based on Farzad and O'Neal lab tests. The average undercharge of these units was measured at 20%. Assumptions again include 100°F ambient temperature and a 700-watt indoor fan.

The corresponding increase in CRI is 11.6% according to their tests.

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92.021 corresponding savings (linear assumption) would be 7.7%.

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The corresponding increase in CRI is 11.6% according to their tests.

Disconnected Ductwork

92.021 The largest set of empirical data on savings from duct sealing alone is Cummings (1990). The savings in that study averaged 18%. The calculation methodology used in this paper provides a good estimate of energy savings, however Cummings' empirical data includes interactions that are not modeled in the Palmeiter calculations.

The CRI is not appreciably affected by duct sealing. If duct sealing reduces the flow the CRI will decrease slightly.

The heating savings from duct sealing is calculated based on sealing 65% of the leaks measured in the initial test. This calculation is detailed in Appendix B.

Fan Off Time Delay

Five sites were run for individual cycles to study the effect of leaving the fan on at the end of the cycle. The air conditioning results are described in detail in Appendix D. Running the fan at the end of the cycle will not affect the CRI.

The savings estimate from lowering the fan off temperature in the heating mode is based on the furnace defining equations in Appendix D. The average $\beta = 2.13$. The average fan off temperature reduction = 12.4°F. The average cycle time is estimated at five minutes (300 seconds).

Correcting an Underfired Furnace

Based on a regression of oxygen in the flue gas against $\frac{\text{actual input}}{\text{rated input}}$, it was determined that the change in steady-state efficiency from correcting the input rate of underfired units would produce a savings of 2.9%.

Anticipator Adjustment

The savings estimate from raising the anticipator to lengthen the cycles is based on the furnace defining equations in Appendix D. Using average values for the hinge point, slope, and fan off, a change from a 270-second cycle to a 300-second cycle will save 2%.

NET LIFETIME BENEFIT ANALYSIS

92.021

The DSSTRATEGIST program gives a number of important outputs including:

Program Benefit - The gross lifetime benefit to the participant and the utility in dollars.

Program Cost - The lifetime program cost in dollars to the participant and to the utility.

Net Benefit - The Program Benefit minus the Program Cost.

Benefit Cost Ratio - The Program Benefit / Program Cost

These calculations were based on the average 1989 use of the pilot sites, 377 therms heating and 3658 kWh cooling. The calculation used lifetimes of 5 years for appliance measures and 15 years for ductwork measures.

Appendix F

Forms and Procedures

Forms and Procedures

92.021

These forms and procedures were used in the 15-unit pilot. The forms were operational drafts and should not be used further without being revised and updated based on the results of this pilot. Rights to use the copyrighted furnace forms were obtained from Sun Power Association. These rights were limited to use for the Fresno pilot.

Form D,AC/F and the Duct Work Form cover the work of the initial team at the house. Form AC covers the work performed during the second visit to the house. Comments pages have been deleted from the forms as they are printed here.

FORM D,AC/F

INSPECTION AND TEST Homeowner ____________________

Address ____________________ City ____________________

Zip Code __________ Home Phone ______________ Work Phone __________

Number of Stories __________ Crawlspace? ________ Attic? __________

Floor Space __________ Year Built __________ How long has owner lived here? ________

Is there an evaporative cooler? ______________ How many times used /wk? __________

Is there a woodstove ? ________ Fireplace? ______ How many fires a week? __________

Number of occupants:	Adults	Teenagers	Children

Technician ______________ Date __________

1. INITIAL INTERVIEW:

Inform the homeowner purpose and procedures of the program. "The program is designed to find and remedy some of the common problems that may not have been found or repaired in the past.

The operation of the air conditioner and furnace will be checked by conducting a set of standardized tests which will determine if anything in the AC, furnace or duct work is causing a lowered efficiency. This means that we will have to run both the furnace and air conditioner a number of times.

There will be noise from drilling holes, while the duct tests with the blower door are being done and while ducts are being repaired.

We are prepared to fix some - "the most common" problems.

We will need access throughout the home and will need their help in finding all the registers.

Let them know how long you will be there.

Has their schedule (thermostat settings, vacation, guests) been unusual the last two weeks . Get specific dates. Is any change in schedule planned in the next two weeks?. ______________

____

____

Any problems with the system DURING THE HEATING SEASON. ______________

____

____

Any problems with the system DURING THE COOLING SEASON. ______________

____

____

What is the approximate age of the air conditioner? __________yrs. Furnace? __________yrs.

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Have you had a visit by a technician to check your air conditioner?______When?__________
Who? ____
What Did they do?____

Have you had a visit by a technician to check your furnace?______ When?___________
Who? ____
What Did they do?____

Who manages the thermostat?________________________ Does anyone else in the house manage it differently? _______________________________ How?________________

Do you "set up/down" your thermostat at night or when away from home each day?______
Summer T-stat settings: "Normal"__________ Night ___________ Away from home ______
Winter T-stat settings: "Normal"__________ Night ___________ Away from home ______

Do you know where your system filter is? ___________

How often do you change it? __________

Do you have any paperwork on the A C ?_______________ If yes could you get it for me now?

INITIAL BLOWER DOOR TEST

2. Install the blower door to pressurize the house.

3. Check all windows and exterior doors. Be sure to close fireplace and wood stove dampers.

4. Check the registers. Have the homeowner help you find all the registers.

5. Check and record wind speed _____, shielding factor is normal_____, exposed without trees_____, behind other buildings_____outside temp_____, inside temp_____,

6. Pressurize the building to 50 pa. and record: **House pressure _____, mid register pressure_____, flow pressure _____, and flow at largest least restricted return _____.**

7. Inform the duct technician about the leakage rate and any distribution problems

8. Open all the plastic flaps over the registers for the flow test.

OUTSIDE UNIT FAMILIARIZATION & PREPARATION

9. Locate outdoor dial thermometer to read temperature of air into the unit.

10. Is the unit installed in a location that will cause air to recirculate through the outside coil?____

11. Record from nameplate: Manufacturer __________ Model ______________

12. Look up the cooling capacity _______ and EER ___________ (in the Blue Book)

13. Convert btu capacity to tons (btu)_____/12,000 = _______ Tons

14. Locate where you will read the voltage to the air conditioning unit.

15. Locate where you will put the amp-clamp to measure current to the air conditioning unit.

16. Turn off the main disconnect.

INSIDE UNIT (and furnace) FAMILIARIZATION & PREPARATION

17. Record from nameplate AC: Manufacturer __________ Model ______________

18. Do you detect any gas leaks? __________. **IF REAL STRONG, STOP! Contact Supervisor.**

19. Turn off main heating system switch. Is there a fuse?_______ If yes, what type and amperage?_____________

20. Record the furnace: Manufacturer __________ Model _____________Input ___________ Type ___________

21. Check to see if there is any carbon in the heat exchanger, draft hood and gas vent. If found record in comments.

22. Is the combustion air adequate?______ How is combustion air allowed into the space (source)?_______________________. **THERE MUST BE A SOURCE OF COMBUSTION AIR.** If there is no apparent source of combustion air, record in comments.

23. Does combustion air come from a heated or unheated space? ________ If the furnace is in heated space, close ALL windows and doors, turn on all exhaust vents in home

24. Is venting system intact? _______. **If no, STOP!, reconnect and record in comments. If fixed, continue, if not fixed, STOP! contact supervisor and record under emergency.**

25. If there are any other problems with the venting system, record condition and materials needed to correct the problem in comments.

26. Does furnace draw return air from the furnace room?_____If yes, try to fix (even if temporary) and record in comments. A blower compartment door that does not fit properly or an open filter slot are considered return air openings.

27. Record gas valve type. (millivolt or 24 volt)______________ **IF THE GAS VALVE IS MILLIVOLT, DO NOT ADJUST THE ANTICIPATOR.**

28. Install digital thermometer to measure delivery and return temperatures. If the heat strip flow rate method is to be used, THIS MUST BE SOMEWHAT DISTANT FROM THE HEAT STRIPS.

29. Drill hole in gas vent two (2) feet from the top of the draft hood for C.O. and draft tests.

30. Install the low amp meter in line with the red wire to the thermostat.

THERMOSTAT INFORMATION AND FIRST CYCLE **PREREAD**

31. Is the thermostat location bad enough to warrant relocation? ______ If so record why
____

32. Thermostat Type: Mercury _____ Snap ________ Programmable ______ Set back_______

33. Check thermostat: Setting _____°F Set back ______ from_____ to ____, is clock ok?______ anticipator settings Heat ______Cool______

FLOW TEST (if using heat strip method) (If using the steady state method go to next section.

34. Make sure the digital thermometer cannot "see" the heat strips

35. Install heat strip in return where it will not catch anything on fire.

36. **START FAN FIRST.** The fan should be on the AC speed as it is now wired.

37. Plug in the heat strip and At EXACTLY 5 minutes record Δ T __________

38. Shut off the heat strips as soon as feasible and calculate the CFM.

AIR FLOW

Air Flow (________ Watts / __________ Δ T) **X** 3.16 = ___________ CFM

Air Flow / Nom. Ton _________ CFM / Tons ___________ = ________ CFM/Ton

Result should be 425 to 450 per ton. If it is substantially less we must find the restriction and/or increase the blower speed. **INFORM THE DUCT TECHNICIAN OF THE RESULTS**

FURNACE AND AIR FLOW TEST **PREREAD**

39. Turn the water heater to pilot and make sure that other gas appliances are not operating.

40. Set the thermostat all the way up. Mechanically restrain from going off.

41. Remove the fan/limit switch cover. (If the furnace is in an enclosed space close the room door behind you. THE HEATING SYSTEM MUST BE OPERATED AS CLOSE TO NORMAL AS POSSIBLE!

42. Turn on main furnace switch. **Start watch to measure time to fan on temperature.**

43. Inspect the flames. Do you notice any white in the flames/pilot?__________________. If yes, record in comments.

44. Record fan on temperature at hot air delivery.____________ **Also, record time to fan on.**

45. Start watch for five minute readings.

46. Do the flames burn differently with the blower operating?_________________. If yes, record in comments.

47. While waiting for heat rise test, if gas shuts off, record temperature at hot air delivery and time.________________. What is the limit switch setting? ________.
Can it be adjusted? _______. What is the location of the limit switch? ________________
If the gas shuts off, record cycled on the limit switch (CLS)

48. Record the thermostat loop amp draw _______

49. **At five minutes,** measure heat rise through the heat exchanger and record delivery temperature minus the return air temperature or cycling on the limit. NO HEAT RISE CAN BE MEASURED IF CYCLING ON THE LIMIT SWITCH!
D. TEMP____- R.A. TEMP____= HEAT RISE____(Always show subtraction)

DO NEXT STEP RIGHT NOW!!

50. **At five minutes,** measure with gas burning: Draft _______, Spillage ________,
C.O. 92.021, **If C.O. is present, open primary air shutter. If spillage is present or draft is not acceptable, check vent for obstructions. Clean out any obstruction. <u>DO NOT CONTINUE WITHOUT CORRECTING THE SPILLAGE</u>**

51. Clock the gas meter. Record the dial used ______and the time for four separate revolutions.
_______;________,_______,_______,_______

52. If the air flow was already measured using the strip heat method, set the thermostat down and skip to FAN OFF section. **If the furnace is being used for the air flow test leave the furnace on.**

53. Turn to manual **COOLING SPEED** fan.

54. Allow the furnace to run to 20 minutes. Be sure it is not cycling on the limit

55. Using the flow hood check the flow at all returns and record ________, ________

56. At 15 record flue temp _____, flue O_2_____ and heat rise ________

57. At 19 record flue temp _____, flue O_2_____ and heat rise ________

58. Set thermostat down.

FAN OFF AND CALCULATIONS

59. Record fan off temperature at hot air delivery.____________

AIR FLOW

Input (3,780,000 / ___________sec per rev) **X** ____Cu.Ft per rev = ________ Btu/hr

SS Output _______ Btu/hr **X** ______________SS Eff. = __________ Btu/hr

CFM (_________ SS.Output / ______ Δ T) / 1.08 = _____ CFM

Air Flow / Nom. Ton _________ CFM / Ton_____________ = ______________ CFM/Ton

Result should be 425 to 450 per ton. If it is substantially less we must find the restriction and/or increase the blower speed. **INFORM THE DUCT TECHNICIAN OF THE RESULTS**

COOLING TEST **PREREAD**

60. Install the amp-clamp to measure the AC unit current.

61. Switch to cooling, turn down the thermostat and restart your stop watch.

62. Turn on main ac switch. **Start watch to measure time.**

63. Record the thermostat loop amp draw ________

64. At EXACTLY 10 minutes record the supply wet bulb _______ then the return wet bulb _____

65. At EXACTLY 12 minutes measure and record the Amps on both legs ____/____to the AC unit.

66. Measure and record the Volts_________

67. OR Watts from house meter test: ______Meter Kh _______# of rev. ______Seconds

68. Record the outdoor air temperature from the outside thermometer________

69. Turn off main switch, circuit breaker or remove fuse. **Remember there can be up to three disconnects necessary.**

INFORM THE DUCT TECHNICIAN THAT HE CAN DISCONNECT ANY DUCTS THAT NEED REPLACING NOW.

CALCULATIONS

70. ENTHALPY CHANGE

________ Return wet bulb (A)____________ Return Enthalpy (from table)

________ Supply wet bulb (B)____________ Supply Enthalpy (from table)

(A - B) _______________ Change in Enthalpy

71. TOTAL OUTPUT

________ CFM X ______ Change in Enthalpy X 4.5 = ___________ Btu/hr.

72. APPARENT INPUT

AC Unit __________Amps. X ________ Volts = _______ Watts

73. ACTUAL INPUT

(_____# of Revolutions X _____ Kh X 3600) / _____# of seconds = _____Watts

74. ENERGY EFFICIENCY RATIO

________ OUTPUT / __________INPUT = __________ **EER**

Result is plotted on the EER Graph. It should be above the minimum line for an air conditioner with the same EER rating or EER 7.8.

REPAIRS AND ADJUSTMENTS

75. IF DIRECT DRIVE MOTOR, Record wiring from motor._______to ________, ________ to ________, ________ to ________, ________ to ________.

76. IF BELT DRIVE MOTOR: Remove belt and inspect for wear. Record belt size________ Record condition and tension. ____________________Measure pulley width, diameter, and alignment and record.__________________________ Realign pulleys if necessary.

77. Visually inspect blower and record cleanliness.____________ If the blower is dirty, remove and clean._____. Also clean the motor, the blower compartment, and the return air plenum.

78. Visually inspect inside coil and record cleanliness.____________ If the coil is dirty, clean. ____________________________.

79. Oil motor and bearings if applicable.__________________ **DO NOT OVER OIL!!**

80. Record filter condition.______________

81. Install a new washable filter and whistle or clean and replace existing washable filter. **MAKE SURE THAT NEW FILTER IS WELL SECURED AND EASY TO REMOVE!!** Record if filter is replaced .____________

82. If the cooling CFM is below 400 CFM, Check if duct restrictions can be removed and be sure they are removed. If no restrictions exist increase blower speed if possible. Record work done
____

83. Is the motor DIRECT DRIVE?_____. If yes, was heat rise over 80 degrees or cycling on the limit switch?_____. If yes, was power wire connected to highest blower speed?_______. If no, reconnect blower motor to highest speed and record.____________________________________ If heat rise is 80 degrees or below, reassemble heating speed as found.

84. Is the motor BELT DRIVE?_____. If yes, was heat rise over 80 degrees or cycling on the limit switch? _____. If yes, were pulley haves tight together? _____. If not, adjust tight together and record new width _______ and new tension of belt _________ If tight together, is there a fuse for the furnace? ______ If yes, install a larger pulley and record new pulley width and diameter. _____________ Always tighten pulley halves first before going to a larger pulley. **DO NOT INSTALL A LARGER PULLEY WHEN THERE IS NO FUSE PRESENT.** If heat rise is 80 degrees or below, reassemble as found.

85. Was belt frayed or damaged?_____. If yes, replace belt and record new size.___________. **MAKE SURE THAT BELT IS NOT TOO TIGHT!**

86. Reset the fan off temperature as close to 90 degrees as possible. Do not set the fan off temperature below 90 degrees. If the original fan off temperature is below 90 degrees, do not reset, unless the client has complained about cool air at the end of the cycle. **RESET THE FAN ON TEMPERATURE AS CLOSE TO THE FAN OFF TEMPERATURE AS POSSIBLE.**

87. Add a 60 sec time delay to the cooling fan control and record all work done including wiring comments____
____

DUCTWORK

88. Visually inspect the air return system from living space. Remove every grill, use a flashlight and mirror, Record all leaks into walls, attics and crawlspaces. ___________________________
____
Repair leaks ____

89. Visually inspect the air supply system from living space. Remove every grill, use a flashlight and mirror, Record all leaks, be very alert for disconnected ducts near the boot. ______________
____
Repair leaks ____

CONTROLS

90. Reset anticipators to correct amps as recorded during the cycles and record new settings
____

FINAL TESTS **PREREAD**

NOTE THAT THESE TESTS ARE TIMED - IT IS ESSENTIAL THAT THE READINGS BE TAKEN AT THE TIME SPECIFIED. **ALWAYS PERFORM THE AIR FLOW TEST (EITHER METHOD) UNLESS NO DUCT SEALING, COIL, FILTER OR BLOWER CLEANING HAS BEEN DONE**

FLOW TEST (if using heat strip method) (If using the steady state method go to next section.

91. **START FAN FIRST.** The fan should be on the AC speed as it is now wired.

92. Plug in the heat strip and At EXACTLY 5 minutes record Δ T ________

93. Shut off the heat strips as soon as feasible and calculate the CFM.

AIR FLOW

Air Flow (_______ Watts / ________ Δ T) **X** 3.16 = _________ CFM

Air Flow / Nom. Ton ________ CFM / Tons _________ = ________ CFM/Ton

Result should be 425 to 450 per ton. If it is substantially less we must find the restriction and/or increase the blower speed. **INFORM THE DUCT TECHNICIAN OF THE RESULTS**

FURNACE AND AIR FLOW TEST **PREREAD**

94. Turn the water heater BACK ON

95. Set the thermostat all the way up. Mechanically restrain from going off.

96. Turn on main furnace switch. **Start watch to measure time to fan on temperature.** (If the furnace is in an enclosed space close the room door behind you. THE HEATING SYSTEM MUST BE OPERATED AS CLOSE TO NORMAL AS POSSIBLE!

97. Inspect the flames. Do you notice any white in the flames/pilot?________________. If yes, record in comments.

98. Record fan on temperature at hot air delivery.___________ **Also, record time to fan on.**

99. Start watch for five minute readings.

100. Do the flames burn differently with the blower operating?________________. If yes, record in comments.

101. While waiting for heat rise test, if gas shuts off, record temperature at hot air delivery and time.______________. If the gas shuts off, record cycled on the limit switch (CLS)

102. **At five minutes,** measure heat rise through the heat exchanger and record delivery temperature minus the return air temperature or cycling on the limit. NO HEAT RISE CAN BE MEASURED IF CYCLING ON THE LIMIT SWITCH!
D. TEMP____- R.A. TEMP____= HEAT RISE____(Always show subtraction)

DO NEXT STEP RIGHT NOW!!

103. **At five minutes,** measure with gas burning: Draft _______, Spillage ________,
C.O. _______,

104. If the air flow was already measured using the strip heat method, set the thermostat down and skip to FAN OFF section. **If the furnace is being used for the air flow test leave the furnace on.**

105. Turn to manual high speed fan.

106. Allow the furnace to run to 20 minutes. Be sure it is not cycling on the limit

107. Using the flow hood check the flow at all returns and record _______, _______

108. At 15 record flue temp _____, flue O_2_____ and heat rise _______

109. At 19 record flue temp _____, flue O_2_____ and heat rise _______

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110. Set thermostat down.

FAN OFF AND CALCULATIONS

111. Record fan off temperature at hot air delivery.___________

AIR FLOW

Input (3,780,000 / __________sec per rev) X ___Cu.Ft per rev = _______ Btu/hr

SS Output ______ Btu/hr X _____________SS Eff. = _________ Btu/hr

CFM (________ SS.Output / _____ Δ T) / 1.08 = ____ CFM

Air Flow / Nom. Ton ________ CFM / Ton____________ = ____________ CFM/Ton

Result should be 425 to 450 per ton. If it is substantially less we must find the restriction and/or increase the blower speed. **INFORM THE DUCT TECHNICIAN OF THE RESULTS**

COOLING TEST **PREREAD**

112. Switch to cooling, turn down the thermostat and restart your stop watch.

113. At EXACTLY 10 minutes record the supply wet bulb ______ then the return wet bulb _____

114. At EXACTLY 12 minutes measure and record the Amps on both legs ____/____to the AC unit.

115. Measure and record the Volts________

116. OR Watts from house meter test: _____Meter Kh ______# of rev. ______Seconds

117. Record the outdoor air temperature from the outside thermometer_______

118. Turn up the thermostat - Check for new 60 sec delay on fan _____________

CALCULATIONS

119. ENTHALPY CHANGE

________ Return wet bulb **(A)**____________ Return Enthalpy (from table)

________ Supply wet bulb **(B)**____________ Supply Enthalpy (from table)

(A - B) _______________ Change in Enthalpy

120. TOTAL OUTPUT

________ CFM **X** ______ Change in Enthalpy **X** 4.5 = ___________ Btu/hr.

121. APPARENT INPUT

AC Unit ___________Amps. **X** ________ Volts = _______ Watts

122. ACTUAL INPUT

(_____92#21of Revolutions X _____ Kh X 3600) / _____# of seconds = _____Watts

123. ENERGY EFFICIENCY RATIO

________ OUTPUT / __________ INPUT = ___________ **EER**

Result is plotted on the EER Graph. It should be above the minimum line for a heat pump with the same EER rating or EER 7.8.

FINAL BLOWER DOOR TEST

124. Check all windows and exterior doors.

125. Check the registers.

126. Check and record wind speed _____,outside temp_____, inside temp_____,

127. Pressurize the building to 50 pa. and record: **House pressure _____, mid register pressure_____, flow pressure _____, and flow at largest least restricted return _____.**

128. Inform the duct technician about any leakage reduction work still needed.

129. Remove all the plastic flaps over the registers if leakage is ok.

FINAL PRESENTATION TO HOME OWNER

Describe what you found.

Describe what you did.

Describe next steps.

DUCT WORK FORM

92/021

DUCT WORK INFORMATION Homeowner ______________________________

Address ______________________________ City ______________________________

Inspector ____________________ Date ______

While the lead technician interviews the home owner:

- put plastic down below the attic access,
- plastic over all the vents in a way that can be taped open for the flow test,
- bring in all your tools to the attic or crawl space,
- close all the doors, windows, attic access, and fireplace/woodstove dampers,
- assist in setting up the blower door and flow hood,
- check and record indoor temperature ____________

After the interview, find out from the lead technician if there any portions of the house that either get too much or too little heat____

____

DUCT WORK FAMILIARIZATION

5. Duct Location____

6. Type (rigid,plastic,al flex,duct board) ______________________ Is duct work insulated?________

7. As soon as the flow test is completed check with the lead technician to see if restrictions are a problem.

7. AS YOU PROCEED RECORD ANY RESTRICTIONS OR DISCONNECTS OF THE DUCT WORK ON THE NEXT PAGE.

DUCT SEALING AND RESTRICTION REMOVAL

8. Remove all fiberglass wrap from joints.

9. Seal all the big leaks first the normal priority is

   - Disconnected ducts
   - Flex duct to plenums
   - Tees and takeoffs
   - Elbows
   - Seams

10. Reinsulate the joints.

11. The goal is less than 50 cfm leakage.

FORM AC

INSPECTION AND TEST Homeowner ____________________

Address ____________________ City ____________________

Technician ____________ Date __________

INITIAL INDOOR COIL FAMILIARIZATION AND PREPARATION

1. Turn off the power supply to the furnace. If a rooftop unit disconnect the thermostat wire at the unit so you can control it there.

4. Go to the unit.

5. Record furnace: Manufacturer ________ Model ____________

6. Record coil: Manufacturer ________ Model ____________

7. Install the supply and return probes to measure wet and dry bulb temperatures.

AIR FLOW TEST **PREREAD**

1. Turn on the blower on high speed.

2. Using the flow hood measure and record the flow at each return grille **A**______ ,**B**______

TURN OFF THE FLOW HOOD BETWEEN EVERY READING AND RECALIBRATE.

CFM

A ________cfm + **B** ________cfm = **K**______ CFM

AIR FLOW PER TON

K_______ CFM ÷ _______Ton = ______CFM/Ton

Result should be 425 to 450 per ton. If it is substantially less we must find the restriction and/or increase the blower speed.

COMPRESSOR UNIT FAMILIARIZATION & PREPARATION

16. Locate outdoor thermometer to read temperature of air into the unit. (5″ to 6″ from outside coil)

17. Record from nameplate: Manufacturer __________ Model _______________

18. Look up the cooling capacity _______ and EER ___________ (in the Blue Book)

19. Convert btu capacity to tons (btu)_____/12,000 = _______ Tons

20. Obtain control by the unit by turning off the main disconnect or disconnecting the wires to the thermostat at the unit..

FIRST COOLING TEST **PREREAD**

21. Switch to cooling, turn down the thermostat.

22. Measure and record indoor wet bulb **L**______, dry bulb **M**______,

23. Install you ammeter to measure the compressor amperage.

23. Turn on the unit. Watch the amps and **Start watch to measure time.**

CONDENSER

24. After start up record: Outdoor dry bulb **N**______

	PRELIM.	FIRST	SECOND	FINAL
Discharge line temp.	______,	______,	______,	______,
Mid condenser temp.	______,	______,	______,	______,
- Liquid line temp.	______,	______,	______,	______,
= Subcooling	______	______	______	______

LOOK UP RESULTS ON THE CHART

EVAPORATOR

25. After start up record:

Suction line temp.	______,	______,	______,	______,
- Evap saturation temp.	______,	______,	______,	______,
= Superheat	______	______	______	______

LOOK UP RESULTS ON THE CHART

COMPRESSOR

25. After start up record:

Compressor amps.	______,	______,	______,	______,

COMPARE WITH RATED AMP DRAW

COOLING EFFICIENCY TEST

26. After 92.021 15 minutes record return wet bulb O______, and return dry bulb P______, supply wet bulb S______, and supply dry bulb T______,

27. Measure watts from house meter test: Meter Kh Z______, # of rev Y______, and seconds U______, Multiplier (if any) V______,

28. Record the outdoor air temperature from the outside thermometer W______,

29. Measure and record indoor wet bulb______, dry bulb______,

30. Pull main switch unit. Using megohm meter read and record______T1 ______T2 and evaluate the results.

TOTAL OUTPUT

31. ENTHALPY CHANGE

O______ Return wet bulb AA______ Return Enthalpy (from table)

S______ Supply wet bulb BB______ Supply Enthalpy (from table)

(AA - BB) = CC______ Change in Enthalpy

32. TOTAL OUTPUT (H_T)

K______ CFM X CC______ Change in Enthalpy X 4.5 = (H_T)______ Btu/hr.

CHECK OF TOTAL OUTPUT

33. SENSIBLE OUTPUT (H_S)

P______ Return dry bulb - T______ Supply dry bulb = = DD______ Temp. split

K______ CFM X DD______ Temp. split X 1.08 = (H_S)______ Btu/hr.

34. LATENT OUTPUT (H_L)

O______ Return wet P______ dry EE______ Return Grains/lb (from chart)

S______ Supply wet T______ dry FF______Supply Grains/lb (from chart)

(EE - FF) = GG______ Change in Grains per lb

K______ CFM X GG______ Change in Grains X .68 = (H_L)______ Btu/hr.

35. CHECK CALCULATION (H_S)

______(H_L) + ______ (H_S) = ______ (H_T)

36. ACTUAL INPUT

(Z______ Kh X Y______ # of Revs. X 3600) ÷ U______ seconds = HH______Watts

37. ENERGY EFFICIENCY RATIO

(H_T)______ OUTPUT ÷ HH______ INPUT = ______ EER

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92.021

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