92.015

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Pacific Gas and Electric Heat Pump Efficiency and weatherization Pilot Project

Field/Technical Report

Final Report
1991

Submitted by:
Building Resources Management Corporation
a subsidiary of
Puget Energy Services, Inc.

Authored By:
John Proctor, Engineering Manager
Brad Davids, Project Manager
Frank Jablonski, Project Coordinator
George Peterson, Energy Engineer

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Executive Summary

INTRODUCTION

The Heat Pump Efficiency and Super Weatherization Pilot Project was initiated to address the problem of a high level of complaints from homeowners with heat pumps in PG&E's Drum Division (near Auburn, California).

OBJECTIVES

There were two major components of the project. These were to:

(1) identify the major problems with existing residential heat pump installations; and

(2) design a system to correct those problems.

The objective of the identification component was to determine the range and frequency of problems at selected heat pump sites. These sites were selected from a pool made up of customers who had complained to PG&E about high electricity bills.

The objectives of the design component were to create a program that would:

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

(2) save ten to twenty percent of the space heating energy for the selected customers;

(3) be able to be implemented at a cost to PG&E of less than $400 per site; and

(4) facilitate increased customer acceptance of high efficiency heat pumps in both retrofit and new construction.

METHODOLOGY

Fifty-one heat pumps, at forty-eight house sites, were selected by PG&E for the pilot project. Each of the locations was visited by a heat pump technician, who used specially designed forms to test, record, and repair each unit. These forms were reviewed by the program manager to determine if the proper work had been done and if the desired results were achieved. If the review determined that the unit needed additional work the technician returned 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

Ninety percent of the houses investigated had at least one major problem with the heat pump or building shell. Solutions to these problems were demonstrated through field testing, and a program was designed to cost-effectively solve the majority of the problems, reducing the heating energy use of the selected customers by an average of 27%, while improving homeowner comfort.

Problems Identified at Sites in Pilot Project

Customer complaints of high bills and poorly operating heat pumps were due to identifiable problems with the heat pump, the heat pump controls, the ductwork, and the building shell. Seventy-three percent of the units had been previously serviced by heating contractors. These previous visits had not found nor solved the problems.

Table A lists the major problems identified at the sites in the pilot project. The program designed through this project would make necessary repairs to the ductwork, heat pump, and controls as indicated in the table.

Table A. Problems Identified in Pilot Project Sites (48 Houses, 51 Heat Pumps)

	Number of Houses with Problem	Problems Solvable through Program
HEAT PUMP PROBLEMS:		
Diffuse Duct Leakage > 150 cfm	33	25
Low Air Flow	24	19
Incorrect Charge	16	16
Disconnected Ducts	16	14
Refrigerant Leaks	10	10
Recirculation Through Outside Coil	9	0
Other Major Problems	6	5
Auxiliary Heat On First	3	3
CONTROL PROBLEMS:		
Manual Thermostat Setback	23	23
“Dueling Managers”	8	8
SHELL PROBLEMS:		
House Leakier than 0.75 ach	15	15*
Less Than R-19 Ceiling	5	5*
No Floor Insulation	2	2*

* Building shell retrofits are an optional component of the program.

Energy Savings

Table B demonstrates the projected energy savings, costs, and net lifecycle benefits for the program, including interactive effects.

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

Average Heating Energy Savings	27%
Average Cooling Energy Savings	22%
Utility Cost	$400
Utility Net Lifecycle Benefit	$459
Participant Cost	$50 to $350
Participant Net Lifecycle Benefit	$2,597

Table C shows the heating energy savings for individual retrofit measures, taken separately (excluding any interactive effects), together with estimated costs and calculated net lifecycle benefits.

Table C. Heating Energy Savings and Cost Estimates for Individual Retrofit Measures

Retrofit Measure	Average Heating Energy Savings	Est. Cost per Site	Percent Utility Contribu-tion	Net Owner Lifecycle Benefit	Net Utility Lifecycle Benefit
Duct and House Diagnostics		$60	100%		
Heat Pump Diagnostics		$30	100%		
Repair Disconnected Ducts	15.0%	$35	100%	$1,638	$562
Repair Diffuse Duct Leaks	7.5%	$150	100%	$952	$147
Install Thermostat Cutout	10.0%	$100	25%	$462	$82
Correct Low Air Flow	5.6%	$50	50%	$312	$52
Install Fan Off Time Delay	3.6%	$50	50%	$167	$23
Repair Leaks and Correct Refrigerant Charge (approx. 30% of units)	18.4%	$200	25%	$777	$215
House Medic (alone)	15%	$530	25%	$1,281	$470
House Medic (after duct repairs are already done)	7.5%	$430	25%	$612	$194

The net lifecycle benefit calculation would change substantially with climate and use patterns as well as changes that shift the costs from the utility to the participant. Using the systems developed in this pilot project, estimates can be made for costs and energy savings in locations throughout PG&E's service territory.

In addition to the forty-eight houses selected for the heat pump study, eight additional sites were selected to study the impacts of a super weatherization program previously implemented by BRMC under the name "House Medic." This program utilizes advanced technology to guarantee that the house is brought to the correct air tightness and that newly recognized heat loss mechanisms are repaired. The program was found to be applicable to this housing stock. We have not included the House Medic weatherization in the recommended program, but report on its results as a sophisticated alternative to existing weatherization programs.

Program Delivery

In order to deliver cost effective service there must be control over the program delivery. Without new controls, the existing heating contractor infrastructure is not equipped to implement a program that effectively locates and repairs the problems found in the pilot. In spite of the fact that many of the sites had recent maintenance by professional personnel, 84% of them had at least one major problem with their heat pump system. Of the sites visited by technicians in the pilot project, 39% had to have return visits due to technician error. These errors were only discovered through a structured system of form review, inspection and feedback. Quality assurance cannot be achieved merely through technician training. It can be achieved through a structured system that combines feedback to the technicians, multiple contractors, inspection of units, and the power to eliminate non-compliant contractors from the program.

RECOMMENDATIONS

The following recommendations for a production program are grouped by scope of application, program design, program economics, program evaluation, implications for new and replacement heat pump incentive programs, and implications for major weatherization programs.

Scope of Application

a. Implement the program in all areas with high levels of Energy Cost Inquiries (ECI's) by heat pump customers.

b. Implement the program on a proactive basis to all heat pump customers that meet specified selection criteria for high heating energy use.

c. Investigate using the program to address residential air conditioning systems.

d. Investigate the applicability of the program to heat pump customers with average heating energy use.

Program Design

a. Use the least costly method of delivering the services. Utilize well-trained technicians to obtain the initial data and repair the most common problems (duct leaks and duct restrictions) on the first visit.

b. Utilize the higher-cost skilled heating technicians only on a fixed cost basis and only to accomplish the standard elements (outdoor cutout and fan time delay) and repairs specified as a result of the first visit.

c. Implement solid control of the program through an experienced program manager. This manager should be responsible for training, certification, form review, feedback, inspection, monitoring, and discipline.

d. Utilize multiple subcontractors in each area to insure that deviations from the program can be corrected.

e. Require subcontractors to handle their own logistics (scheduling of site visits, etc.) to meet the requirements and quality of the program.

f. Consider offering additional services such as major weatherization and extensive heat pump repair, etc. on a fixed-cost basis (with a reduced incentive level) to the customer.

Program Economics

Achieve maximum cost-effective energy savings for each site by combining PG&E subsidies with customer contributions. The ideal customer contribution would achieve the highest possible energy savings at the lowest possible utility cost. It is likely that this would result in PG&E offering the the initial visit that accomplishes the most cost-effective items free or nearly free. This would overcome suspicion, obtain maximum participation, and insure that these measures are completed. A lesser incentive could be offered for subsequent and less cost-effective items.

Program Evaluation

Complete a long term before and after utility bill analysis on the homes in the pilot project and on any future expanded program. Only through such analysis can the true effect of these programs be determined.

New and Replacement Heat Pump Efficiency Programs

If incentives are considered for new heat pump installations, these installations should be held to strict criteria, including:

- testing of initial air flow, COP, and duct leakage
- accessible coil and filters
- ductwork sealed with mastic

Major Weatherization Programs

House Medic should be evaluated against actual measured savings from other weatherization options. It should be tested on a larger scale with adequate crew training.

SUMMARY

The Heat Pump Efficiency and Super Weatherization Pilot Project has resulted in the design of a program that can reduce selected heat pump customers' energy use by over 20%. This program has the potential to significantly improve customer satisfaction with heat pump performance, resulting in increased electric heating customer retention.

Information developed in this project has implications for the approximately 50,000 heat pumps in PG&E's service territory. It may also have implications for residential air conditioning units. The extent to which the findings of this project can be applied to other PG&E districts must be determined through further studies.

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I. Introduction

A. BACKGROUND

Building Resources Management Corporation (BRMC) was selected and contracted by Pacific Gas and Electric Company (PG&E) to complete a pilot heat pump efficiency and weatherization project in PG&E's Drum Division, located in the area of Auburn, California. Because of high levels of complaints to PG&E by homeowners with heat pumps, the investigation focused on what could be done to improve the efficiency of residential heat pumps in actual field installations. Fifty-one heat pumps were included in the pilot project to ensure that a variety of typical problems would be encountered.

With input from BRMC, PG&E hired a local heating contractor to provide two experienced heat pump technicians for the project. In addition, BRMC hired a local weatherization contractor to work under BRMC's supervision to test duct repair and advanced air infiltration control measures. PG&E scheduled the initial site visits. Follow-up visits were scheduled by the contractors. BRMC provided overall program management, including technical supervision, form design, form review, field inspection, infiltration testing, and reporting. Work began on the first house November 30, 1989.

B. OBJECTIVES

The two major components of the Heat Pump Efficiency and Super Weatherization Pilot Project were to: (1) identify the major problems with existing residential heat pump installations; and (2) design a system to correct those problems.

The objective for the identification component was to determine the range and frequency of problems in heat pump houses with customer complaints to PG&E.

The objectives of the design component were to create a system that would:

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

(2) save ten to twenty percent of the space heating energy for the selected customers;

(3) be able to be implemented at a cost to PG&E of less than $400 per site; and

(4) facilitate customer acceptance of high efficiency heat pump programs for retrofit and new construction.

II. Methodology

A. SITE SELECTION AND SCHEDULING

The communities of Cameron Park, Lake Wildwood, Lake of the Pines and Alta Sierra were selected by PG&E for the pilot project. These communities were selected because they were served by different heating contractors, had different histories of interaction with PG&E, and they had sufficient numbers of potential participants. The potential participant pool supplied by PG&E consisted of customers who met two criteria:

- were categorized as Energy Cost Inquiries (ECI's) by PG&E between December 1, 1988 and December 1, 1989; and
- had an annual electricity use exceeding 14,600 kWh in that period.

This selection criteria resulted in an original pool of 231 customers: 102 in Cameron Park, 46 in Lake of the Pines, 38 in Alta Sierra and 45 in Lake Wildwood.

This pool was further screened to insure that each used electricity for winter heating. The criterion was that the average winter heating use exceed 30 kWh/day. (Average winter heating use was calculated by subtracting the average daily use in September from the average daily use in December, January and February.) Eliminating potential participants with inadequate data and those who failed to meet the 30 kWh/day criteria reduced the pool to 116 customers.

Appointments for heat pump technician visits were scheduled by two well-trained individuals in the Auburn office of PG&E. They found it difficult to schedule 50 customer visits in spite of the fact that the program was free to participants.

The predominant reason people stated for refusing the service was that they had switched to another heating fuel, generally to a pellet or wood stove. Some of these individuals indicated their disdain for PG&E with comments such as "I unplugged you guys." A smaller group had electric resistance heat and the program did not apply. A few people said, "I'm not interested" or "I've already had it fixed." The attitude toward PG&E expressed by Lake Wildwood residents was particularly negative and suspicious.

While the selection criteria targeted customers with high heating energy use, data from one community indicated that the customers with the *highest* energy use were less likely to end up as participants in the program, due to reasons noted above.

Ultimately 51 heat pumps were tested and retrofitted. These heat pumps were in 48 houses. Blower door tests were run on 46 of these 48. The houses not tested were due to scheduling problems with the participants. The weatherization crew worked on the diffuse duct leakage in 10 of the 48 houses and 3 of these 10 had computer monitoring equipment installed for more detailed analysis.

In addition to the 48 houses above, 8 additional sites were used to test the applicability of an advanced "super weatherization" technique to reduce heat loss due to air leakage and air movement.

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) field tests were refined to rapidly and accurately determine and solve the problems found;
3) the work that was done in the field actually accomplished its intended objective, that is, the heat pump and distribution system actually performed better than before the site work;
4) 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, modifications, repairs and retrofits, and final testing.
2) Data was recorded for every step of the process so that:
    - the condition of the heat pump, distribution, and structure could be accurately analyzed;
    - the performance of the technician could be determined;
    - the applicability of the testing and retrofit methods could be evaluated.
3) 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;
    - if the processes involved were accomplishing the desired results or needed to be streamlined or changed.
4) The program manager gave the feedback, ordered the follow-up visit or made the revisions as necessary.
5) The sites were inspected to determine if the final condition of the units was being accurately reported and that the modifications were in place and operating properly.

Detailed procedure forms utilized by the technicians and inspectors are contained in Appendices C, D, and E.

C. INITIAL SITE TESTING

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

1) What are the problems with the heat pump systems?
2) What is the relative frequency of these problems?
3) What are the building shell problems?
4) Are high bill complaints due to high thermostat settings as previously reported?

The initial site tests performed on the heat pump, the heat pump controls, the building shell, and the ductwork determined the mechanical or control 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.

The initial site tests performed by the heat pump technician are summarized below, and are detailed on the Efficiency Improvement Procedure Form in Appendix C.

Heat Pump Testing

Initial measurements taken on the heat pump included air flow, heat output, and apparent electrical input. These tests allowed calculation of the heat pump efficiency (instantaneous apparent COP).

The air flow measurement was performed by running only the indoor fan and strip heater. The watts to the strip heater, and the mixed supply, and the mixed return temperatures were measured. A single calculation, based on the heat capacity of air, determined the air flow necessary to achieve the measured temperature rise for the measured input watts.

The output of the compressor stage was determined at five minutes in the cycle. With the compressor running and the strip heat off, the supply and return temperatures were measured. Knowing the air flow and the temperature increase, the output in watts was calculated.

The apparent input wattage was determined by measuring the applied voltage and amp draw at a standardized time in the cycle.

Dividing the output by the apparent input gives the instantaneous efficiency of the heat pump. This efficiency is dependent on a number of parameters, including the condition of the heat pump, the outdoor temperature, the indoor temperature, the air flow, and the amount of refrigerant charge in the unit.

$$\text{Output/Apparent Input} = \text{Apparent C.O.P.}$$

Control Testing

Initial control investigation included strip heat actuation timing, occupant thermostat control patterns, defrost control timing, overall thermostat function, and thermostat type.

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.

After repair of any catastrophic duct leaks, 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 air flow through the fan was measured. Air flow through the fan gives the air leakage out of the house. This procedure was repeated at other house pressures in order to increase the accuracy of the measurement. The final results were calculated on a Sharp PC 1282 Computer, using the Minneapolis Blower Door Computer Program. This program corrected the air flows to an air density of .075 pounds per square inch.

Eight additional houses were more intensely investigated for building shell problems. This procedure is discussed in a subsequent section of this report titled “House Medic Procedure.”

Ductwork Testing

Leakage in the heating system ductwork was determined in three ways. First, the heat pump technician visually checked for disconnected ducts and other catastrophic leaks. The building shell measurements included two blower door tests: the “whole house” test described above, and another with all heating supply and return registers covered with a light plastic film. The plastic effectively sealed the ductwork from the house. This second blower door test measured the same leakage as the first blower door test minus the duct leaks. Subtracting the leakage rate of the “ducts excluded” test from the “whole house” test resulted in a measure of the duct leakage.

The third measurement of the duct leakage was the “flow hood” test. This test utilized the 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 measured the air flow through the register, giving a measure of the duct leakage.

Discussion of Potential Errors in Initial Site Testing

The most critical error may result from misplacement of the thermocouple too near the strip heat. When this happens the thermocouple “sees” the radiant heat and gives an elevated temperature reading. Consequently a lower air flow and COP is calculated. The problem is easily avoided by correct thermocouple placement. This error is suspected when the technician reports low air flow and COP, but is unable to find the cause of the air flow problem. The procedure for proper thermocouple placement is part of the technician form.

The test method of measuring the voltage and amperage of the compressor and calculating the apparent watts does not yield true watts. The results cannot be used to compare to manufacturers' published COP, and input ratings. However the apparent wattage is useful to compare the relative efficiency of one test condition over another. This test method is easier to perform, and sufficiently accurate for our purpose.

All of the blower door tests were done in the pressurization mode. This does not produce any significant error in itself, but caution must be exercised in comparing these results with results from depressurization tests. Pressurization testing may produce up to 15% higher leakage rates than Depressurization.

The two duct leakage tests produce different results. The subtraction method of the two blower door tests produces higher pressures in the ductwork than the "flow hood" test, resulting in higher measured leakage rates. Both the "whole house" and the "ducts excluded" blower door tests measure a large amount of total leakage. The result is that even small percentage errors can mask the true duct leakage when the duct leakage is small.

The "flow hood" test underestimates the actual leakage when the test register is attached to a restrictive duct. This is especially true with leaky ducts. Restrictive ductwork on the test register should be noted. Having evaluated both methods during this program, we recommend the "flow hood" method of duct leakage testing for future implementation.

D. FIELD RETROFIT

The field retrofit methodology (Heating Technician Procedure, Ductwork Procedure and "House Medic" Procedure) was designed to answer the following:

1) Can the technicians employed by existing heating and cooling contractors deliver a program that actually accomplishes heat pump efficiency improvements to near theoretical potential?
2) What are key parameters, able to be easily measured in the field, that will indicate the efficiency of a particular heat pump and the potential savings?
3) What is the measurable efficiency increase due to systematic retrofits?
4) Can existing weatherization contractors' technicians deliver a program that effectively diagnoses and repairs problems in the ductwork and the building shell?
5) Can BRMC's "House Medic" system be applied to these homes?

Heating Technician Procedure

The heating technician procedure contained in Appendix C is a refinement of manufacturers' testing methodology, the work of other researchers including Leon Neal (1990), and criteria developed from manufacturers' data. It is a field operational method that tests, modifies and verifies efficiency improvements on heat pumps.

The initial testing of the heat pump is described in the "Heat Pump Testing" portion of this report. The results of the initial test determine what modifications will be accomplished on each unit.

The procedure guides the technician through the most common and easily solved problems, such as low air flow, to the more time-consuming and less prevalent problems, such as improper charge. Once adequate airflow is obtained a simple non-intrusive test (the COP test) is run. When the results are plotted against expectations the condition of the heat pump can be determined. This generic system is necessary because technicians in the field do not have the ratings for all these heat pumps with them. Results below expectations point to problems in the compressor loop of the heat pump.

The procedure used in the pilot took four to eight hours to complete. If the ductwork portion is moved from the heating technician procedure, and the heat pumps are prescreened, the amount of time necessary to repair a unit could be predicted with accuracy. Most units would require 2 hours of technician time. Heat pumps with refrigerant leaks would require up to 6 hours of repair time.

Duct Leakage Procedure

The duct leakage procedure contained in Appendix D is a refinement of previous work by the authors and the work of other researchers, including John Tooley (1989). It tests, reduces, and verifies the distribution leakage of heat pump ductwork.

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

The procedure involves sealing the ductwork beginning with the most critical locations. These critical locations are disconnected ducts, returns open into the attic, crawlspace or walls and large leaks at the boots behind the registers. Large leaks are termed catastrophic leaks. The work progresses to other leak locations based on the probability that significant leaks occur there. During the procedure insulated joints are unwrapped, sealed with mastic, and rewrapped. This process is designed to eliminate catastrophic leaks and substantially reduce diffuse leaks.

Repairing catastrophic duct leakage and significantly reducing diffuse leakage can be accomplished by a trained individual in 6 hours or less.

Blower Door Testing

Blower door testing has been added to weatherization programs to insure that the work done actually has a significant effect on the leakage area of the structure. The addition of extensive crew training and improved controls substantially improves the energy savings as measured by evaluations of past programs.

The blower door measures the total leakage area of a building, but cannot distinguish between holes that normally have tiny, small or large pressures across them. The result is that before and after blower door measurements are not predictive of the actual savings for a particular house.

"House Medic" Procedure

The "House Medic" program, developed by BRMC, is based on previous work by Proctor (1988) and other researchers, including Dutt (1983) and Harrje (1984). It is a step beyond adding a blower door to standard air infiltration reduction programs. The House Medic program is designed to direct the technicians to the leaks that have the highest pressures across them. The result is that the House Medic technician usually spends 75% of the time in the basement and attic. Other than a few large holes (such as missing windows and open fireplace chimneys), the "hot spots" are typically in the attic and basement. These large holes are repaired quickly and cheaply.

Forms and procedures utilized direct the technicians not only to the leaks with the highest average pressure across them, but also to convective loops and wind washes. A convective loop is usually a vertical surface that has an air space inside. Open convective loops remove heat from the building by allowing cold air to drop from the attic. This cold air is then heated as it rises along the inner surface of the wall. A convective loop is not detectable by pressurization methods unless it also communicates with a significant leak to the interior of the house. Under proper conditions an infrared scanner would assist in finding these locations. The House Medic does not use a scanner, but uses a form-based systematic approach to assist in finding these significant points of heat loss. Many open convective loops are physically the same as major leakage sites (open end walls, open interior walls, etc.)

Wind washes cause heat loss in the same manner as convective loops. Heat is lost as the exterior surface of the drywall (or equivalent) is cooled by the *movement* of cool air against that surface. In the case of the wind wash, this air movement is caused by wind conditions. The classic example of a wind wash is open crawl space vents on opposite sides of the house. This is sometimes accompanied by the addition of batt insulation loosely placed between the joists. This provides a "wind tunnel" to funnel the movement of cold air against the bottom of the floor.

House Medic is a system designed to accomplish high production and increase the number of significant leaks detected. For houses in this project the work uses four technicians for a total of up to 4 hours, or 16 person-hours. Each crew can complete two houses a day.

E. SHORT TERM MONITORING

The short term monitoring, together with the results of the field retrofit, was designed to answer the following:

1) What is the estimated efficiency reduction and electrical cost increase due to poorly operating mechanical systems for the selected customers?
2) What are the estimated savings from the pilot project field retrofit work?
3) What are the potential and achievable savings that result from a heat pump program?

The short term monitoring provided a detailed description of parameters relevant to energy use and program savings. The following items were studied:

1) Occupants' thermostat management;
2) Optional thermostats;
3) Strip heat use and controlling factors;
4) Heat pump cycle details to determine the effect of run time on COP;
5) Defrost cycle occurrence and energy use;
6) The effect of reduced air flow on COP;
7) Building balance point temperatures;
8) Building and system parameters for a linear energy use model, to predict control strategy savings;

Three houses were chosen for the short term monitoring study on the basis of geographical distribution and occupant willingness. Two of the sites were in Alta Sierra and one was in Cameron Park. Table D provides a summary of the sites.

Table D. Short Term Monitoring Sites			
	Site #154	**Site #366**	**Site #482**
Location	Alta Sierra	Cameron Park	Alta Sierra
No. of Residents	2 adults	3 adults, 1 child	2 adults
House Size (ft^2)	2680	1779	2200
Heat Pump Type	unitary	split	unitary
Heat Pump Capacity	57,000 Btu/h	36,000 Btu/h	60,000 Btu/h

A data acquisition system (DAS) was installed at each site. At the end of each heat pump cycle, the DAS recorded the information in Table E. The DAS also recorded the hourly data listed in Table F.

In order to provide a detailed look at specific cycles the DAS was selectively set to record information on all data points every 12 seconds.

Table E. Data Collected Every Cycle	
Time of Day	Condensor Temperature
Supply/Return Temperature Difference	Compressor kWh Usage
Outdoor Temperature	°F-minutes of Delivered Heat
Indoor Temperature	Mode of Operation
Buffer Space Temperature	Run Time of Mode
Evaporator Temperature	New Mode of Operation

Table F. Hourly Data	
Time of Day	Indoor Temperature
Maximum Supply Temperature	Buffer Space Temperature
Minimum Return Temperature	Compressor kWh Usage
Outdoor Temperature	°F-minutes of Delivered Heat

III. Results

A. RESULTS OF INITIAL SITE TESTING

The frequency of problems identified on the program houses are shown in Table G. Ninety percent of the houses studied had at least one major problem with the heat pump system or the building shell. Of the 48 houses studied in the pilot program, 33 had 2 or more major problems. Only 1 house was without a heat pump, building shell, or control problem.

Table G. Frequency of Problems Identified (by Site)

	Percent with Problem
HEAT PUMP PROBLEMS:	
Diffuse Duct Leakage > 150 cfm	70%
Low Air Flow	48%
Dirty Coil (37%)	
Dirty Filter (18%)	
Restricted Ductwork (14%)	
Disconnected Ducts	31%
Incorrect Charge	31%
Refrigerant Leaks	20%
Leak at Schrader Valve (6%)	
Leak at Previous Repairs (4%)	
Other Leaks (10%)	
Recirculation - Outside Coil	18%
Other Major Problems	14%
Strip Heat On First	6%
CONTROL PROBLEMS:	
Manual Thermostat Setback	48%
"Dueling Managers"	17%
SHELL PROBLEMS:	
House Leakier than 0.75 ach	31%
Less Than R-19 Ceiling	17%
No Floor Insulation	4%

House and Duct Leakage

The results of the house and duct leakage tests are detailed in Appendix I. The house leakage information is summarized in Figure 1. If the two outliers are eliminated the median air change rate (at 50 Pa) is 10.82.

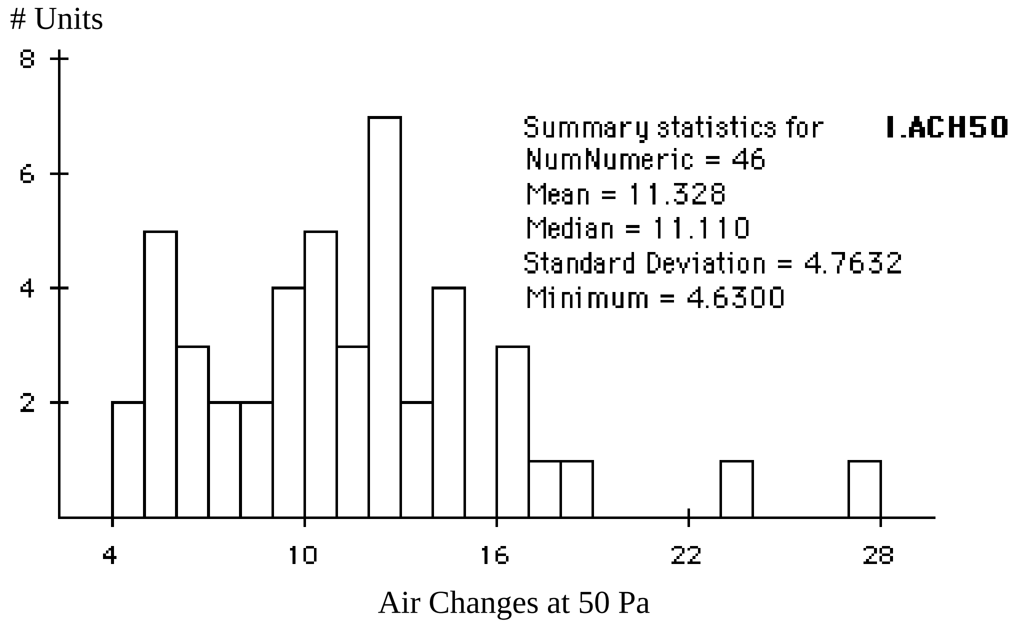


Figure 1. House Leakage Information

Low Air Flow

The primary cause of low air flow is dirty inside coils. Once the coil is dirty the only solution is to clean it. But filter maintenance is a critical factor in the cleanliness of the coil. Figure 2 shows the reported filter maintainance patterns for the participants.

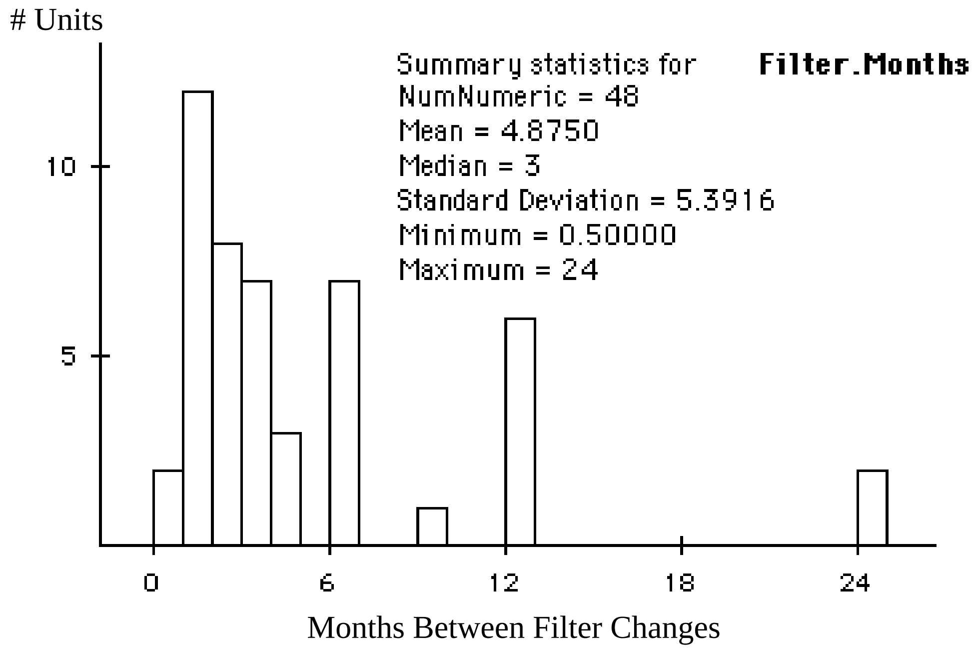


Figure 2. Reported Filter Maintenance Patterns

Customer Comments

This program involved much contact with the house occupants, many of whom were anxious to share their thoughts on heat pumps, energy prices, etc. Beginning with the initial contact, it was surprising how many people, in their words, “hate heat pumps.” Often when the technician or inspector started the interview the first statement from the participant was, “Well, you have to understand that I don’t care for heat pumps.” The reasons varied, but the two most frequently mentioned problems were high electricity bills and poor comfort levels. Often, it was the *combination* of those two factors that created animosity toward heat pumps.

One individual complained that his house remained cold when the temperature was below 40°F. The inspection revealed that his auxiliary strip heat had never been connected, despite the fact that he had had two previous service calls. Two months after the strip heat was properly connected he was ecstatic, telling the inspector, “This works great! I can get heat!”

The negative image of heat pumps is often reinforced by service people who don't find and solve the problems. Many participants reported interchanges with service personnel along the lines of: "I'm sorry, this heat pump is doing the best it can. If you'd like, I can put in an efficient propane furnace for you."

B. RESULTS OF FIELD RETROFIT PROGRAM

The major effect of the field retrofit program was to change the critical parameters of heat pump performance from a broad bell curve to a tighter curve centered near the optimum for each parameter. As a result, there was a large efficiency improvement on the worst heat pumps, and lesser gain on those performing closer to their intended design.

Restricted Air Flow

Low air flow was the most prevalent problem discovered in the program heat pumps. The effect of low air flow has been proven to be detrimental to the efficiency of fossil-fueled forced air furnaces (Proctor, 1984 & 1986).

Intensive furnace cycle testing has shown fossil-fueled forced air furnace efficiency decreases approximately 1.2% for a 10% reduction in air flow but the problem is five times as great with heat pumps. On a heat pump a 10% reduction in air flow (below the target of 425 dry coil cfm) will increase use by 6.6%. Figure 3 is a partial regression plot that shows the effect of air flow on the COP of the heat pumps studied.

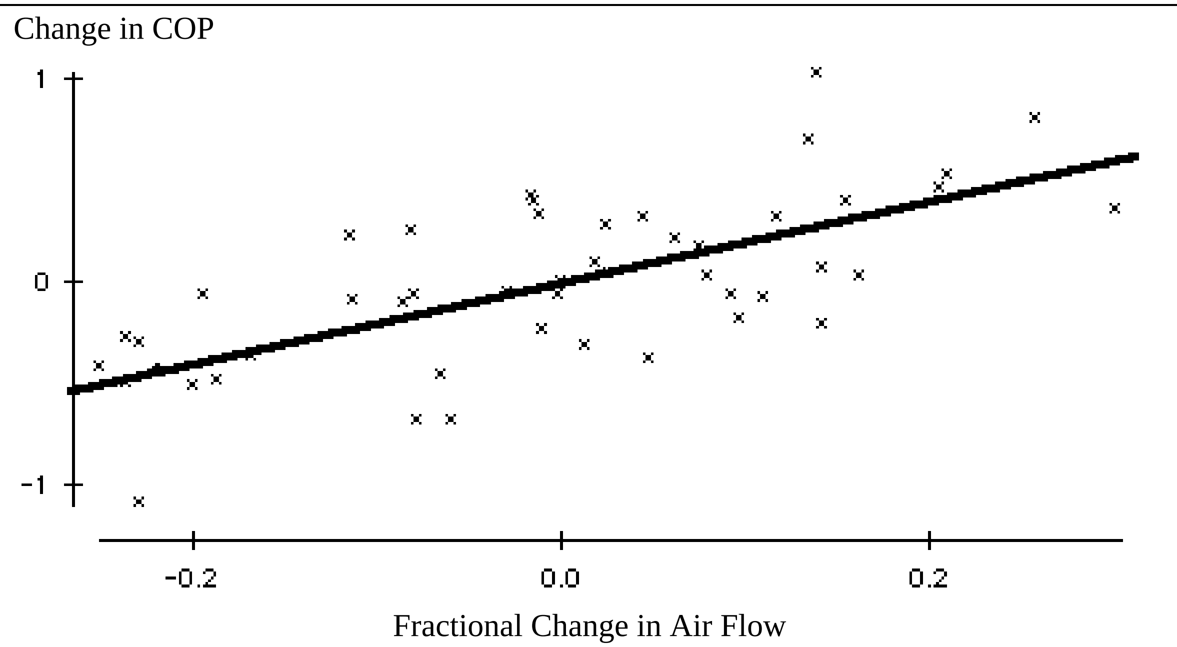


Figure 3. Effect of Air Flow on COP

High air flow also causes problems. If the air flow is too high, the unit performs efficiently, but the occupant often complains of “cold air from the registers.” In addition high air flow creates higher duct pressures, which increases leakage from the ducts.

Low air flow is not only the most common problem, but also the most likely to go unrepaired. One homeowner had complained numerous times about high bills and poor heat delivery. The technician found that the return duct was closed off where it ran through an enclosed chase to the attic. Even with the other return partially open this heat pump was only getting 61% of the design air flow. When we reported the situation to the homeowner she said, “Why hasn’t anyone else found this? I’ve had contractors and PG&E out here for five years. All they could ever tell me was, ‘heat pumps just work that way.’”

Low air flow 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. Most technicians do not know how to do the air flow test using the strip heaters. Neither of the technicians involved in this project had ever done it before.
2) Indoor coils are often accessible only with extreme perseverance.
3) Technicians do not regularly work on ducts. Most technicians concentrate either on repairs to the heat pump itself or on selling a replacement unit.

The field work corrected 56% of the low air flow problems. The initial and final distribution of air flows are shown in Figures 4 and 5. For the units corrected, the resulting savings from this item is estimated at 5.6%. (Savings will also occur in the cooling season.) Savings in the order of 8% were predicted by the model in Krafthefer et al.

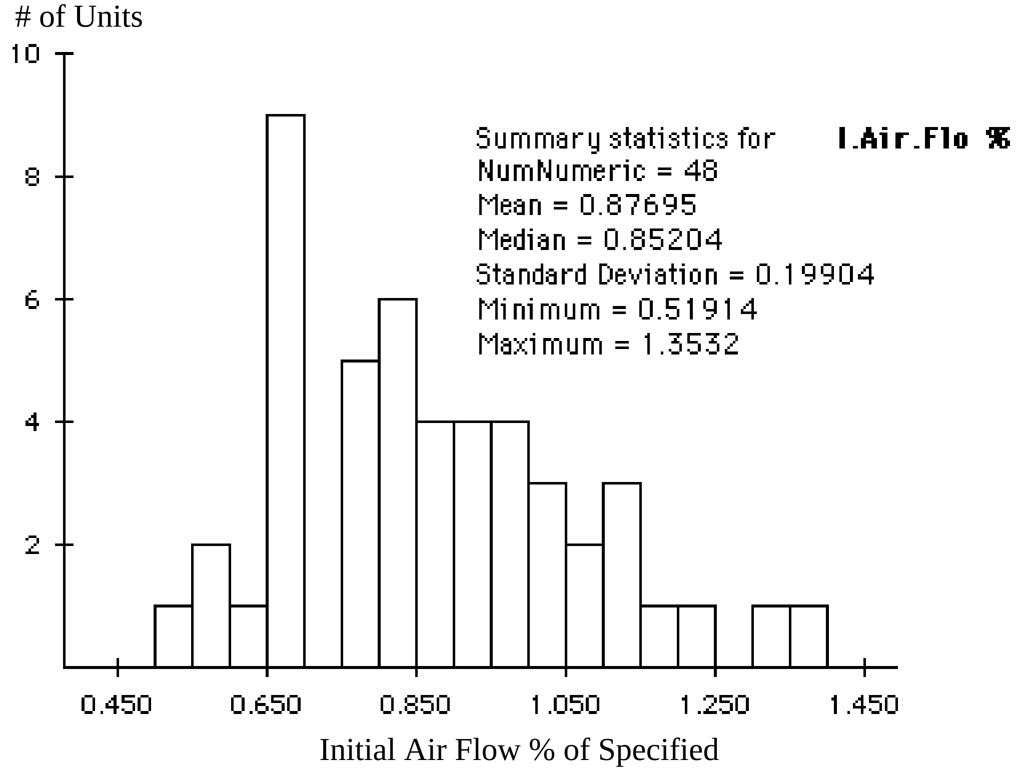


Figure 4. Initial Air Flow Distribution

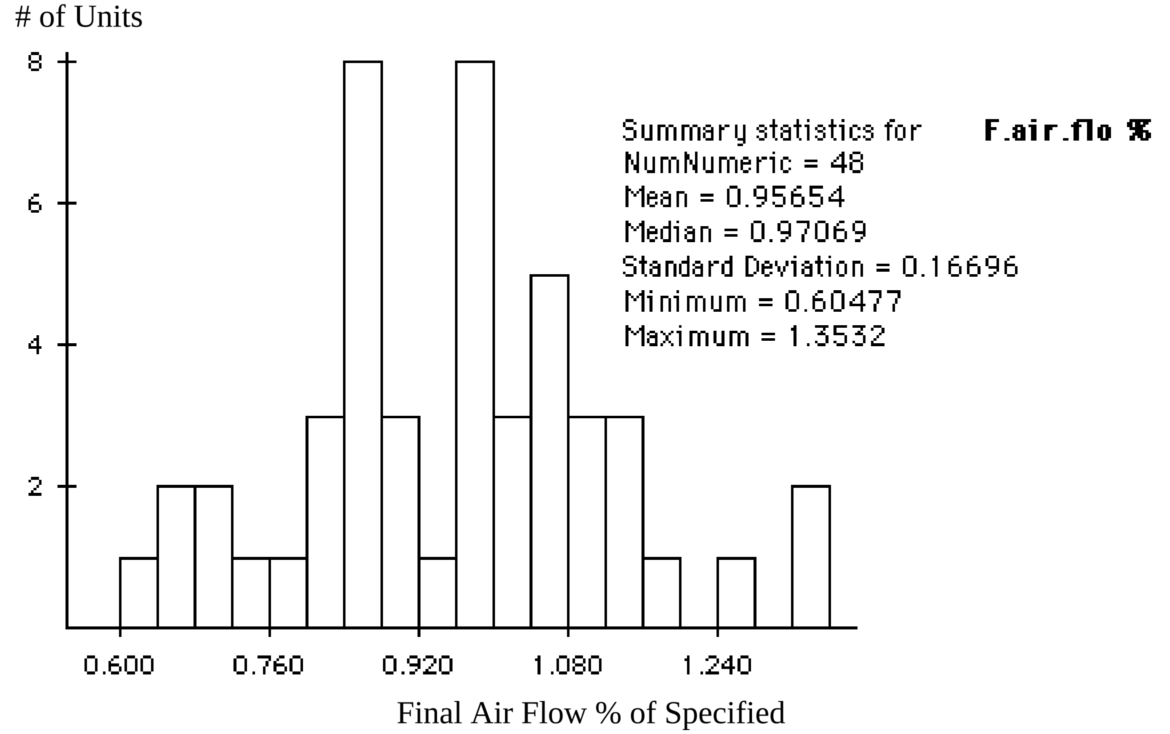


Figure 5. Final Air Flow Distribution

Improper Refrigerant Charge

Improper charge was the second most prevalent problem discovered with these heat pumps. It occurred on 31% of the units.

In the field, most heating technicians make the determination of proper refrigerant charge through guesswork. One participant watching our technician ensure that the unit had the correct charge commented, “Bill (the technician that had been there two weeks before) didn’t even use gauges. He said he didn’t find any leaks but he would ‘fill it up.’ ” Our technician found that this unit had leaks at both Schrader valves and had moisture in the system. (Moisture in the system will cause compressor failure.)

It is not surprising that many of these units have an incorrect charge. 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. When parts of the system are replaced or repairs are made hastily, brazing connections to the new part are often leaky. Technicians often add refrigerant without finding the cause.

Checking for correct refrigerant charge is a difficult task in older heat pumps. The manufacturers’ charts are missing. Subcooling and hot gas temperature were tried as generic methods of determining charge. Neither gave us the same results as the manufacturers' charts. The procedure used was to "chase the COP." This process consisted of adding and removing charge until the peak COP was determined. In order to avoid harming the unit, it was done while monitoring the suction and head pressures. This method is not foolproof. As the outdoor temperature changes the peak COP can occur at different amounts of charge.

During this project 100% of the identified refrigerant charge problems were repaired. As a result the savings from this item on the 16 units improperly charged is estimated at 18.4%.

Control Problems

Contrary to expectations, high thermostat settings were not found to be a problem in the houses studied. In fact, the thermostat settings were generally quite low. Figure 6 summarizes the "Normal" reported set points.

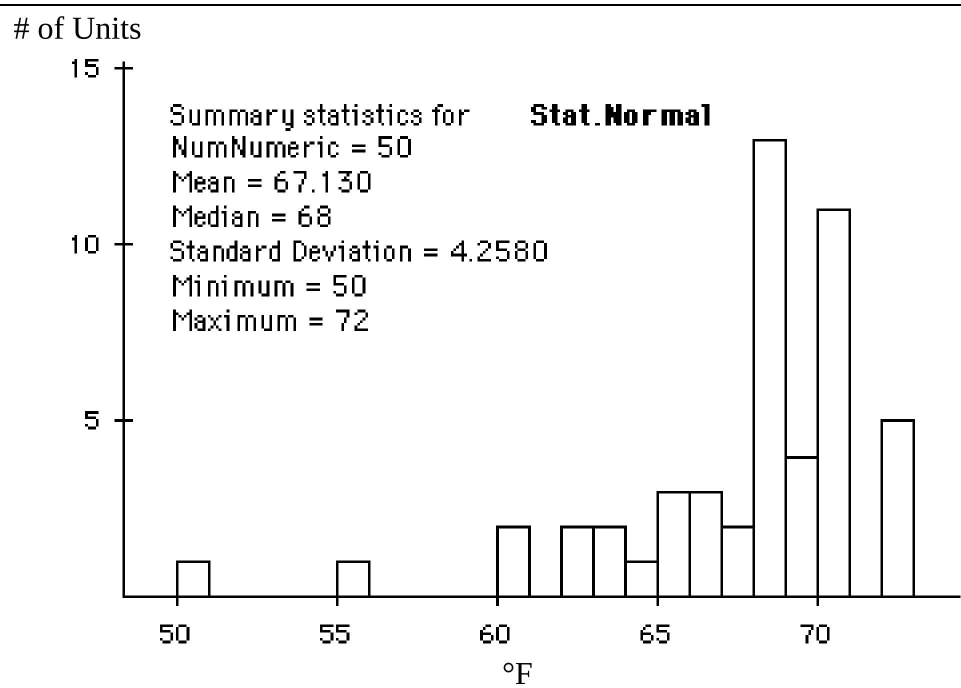


Figure 6. Reported Thermostat Setpoints

While the set points were not a problem, the typical control pattern was. Sixty five percent of the participants used control strategies that often resulted in unnecessary strip heat use.

The two common control problems in the heat pumps studied were:

1) the use of setbacks
2) "dueling managers"

Thermostat setbacks lead to strip heat use and increased bills. The results from the short term monitoring confirmed what we had noted in our interviews. Even people who think they know how to stay out of strip heat by “moving the thermostat up a few degrees at a time” cannot because the thermostats do not have a large enough differential between first stage and second stage.

Dual (and dueling) thermostat managers were common occurrences in these houses. Two adults often have different views of how the heat pump should be managed. Usually one keeps turning it up (sometimes a little at a time) and the other keeps turning it all the way down. This results in most of the heating energy being supplied by the strip heaters. Consequently heating bills increase, the “turn it down” party feels more justified in his/her behavior, and they both get angry with the utility for the high bills.

Two solutions to these thermostat control problems were studied. The first was a programmable digital heat pump thermostat that slowly ramps up the temperature in the early morning to achieve the proper indoor temperature when the occupants get up. This will achieve the desired temperature without strip heat. We found that it did not have as high an acceptance rate as expected.

Some participants in the pilot project:

1) overrode the device during the day (three known)
2) didn’t understand how to reprogram it even though instructions were patiently given in both verbal and written form (two known)
3) refused installation of the device (two)
4) requested that it be removed—“put my old thermostat back” (one)

The second solution was a outdoor thermostat that cutout the strip heat whenever the outdoor temperature was above 35 to 40°F. This device met with higher acceptance since it was invisible to the participants and required no change in behavior on their part. This device also provides a very good signal of compressor stage problems. The only problems with the device came when the temperature dropped below 35°F and the strip heat would still not come on. Neither of the three models we used were judged to be sufficiently accurate for use on a production program. (We would recommend a fixed temperature device with a small deadband such as the Accustat™ for this application in the future.)

Fifty-seven percent of the homes received the programmable digital thermostat. While 94% of the homes had the outdoor cutout installed. Thirty-one units that used set backs or fought over the controls had the cutout installed. The savings potential for these units is 16%. However these cutout thermostats have shown to vary considerably in actual cutout temperature. We therefore estimate the achieved savings at 8%.

Defrost Timers

Defrost controls vary greatly from unit to unit, but a high percentage of these old heat pumps had timer-actuated defrost controls. Each defrost cycle results in an additional load of .069 kWh per cycle. In the climate where these units are operating, a defrost timer setting of 90 minutes is sufficient. Twenty-six percent of the units with adjustable timers were set to cycle more frequently than 90 minutes; those timers were reset to 90 minutes.

Recirculation Through the Outside Coil

Builders have a strong desire to hide the heat pump. That means tucking it away behind the house or in a step-back in the wall. Sometimes a deck is built over the heat pump. Whenever such actions result in reducing the passage of outdoor air from the coil to the atmosphere, there is a reduction in efficiency. In one case the deck trapped the cooled exhaust air, lowering the temperature of air to the outside coil to 10°F below ambient and reducing efficiency by 11%. We were unable to convince anyone to tear down their deck for the sake of a lower heating bill.

Building Shell

In some cases insulation values were below Title 24 values. Lack of insulation, however, was not the predominant building shell problem. Excessive air infiltration and duct leakage were the most common shell problems in the homes studied. The natural air changes calculated using the LBL model exceeded .75 ach on 31% of the homes.

The only building shell measures tested in this pilot were the eight “House Medic” houses. These houses were not worked on in any other way. The purpose was to determine if this technique could be applied to this housing stock. House Medic was implemented using a crew previously trained in weatherization using the standard California package. With feedback, the crew steadily learned how to apply the program. As a result the ductwork sealing, convective loop sealing, and whole house sealing became progressively more effective. This is shown in Figure 7 and Table H.

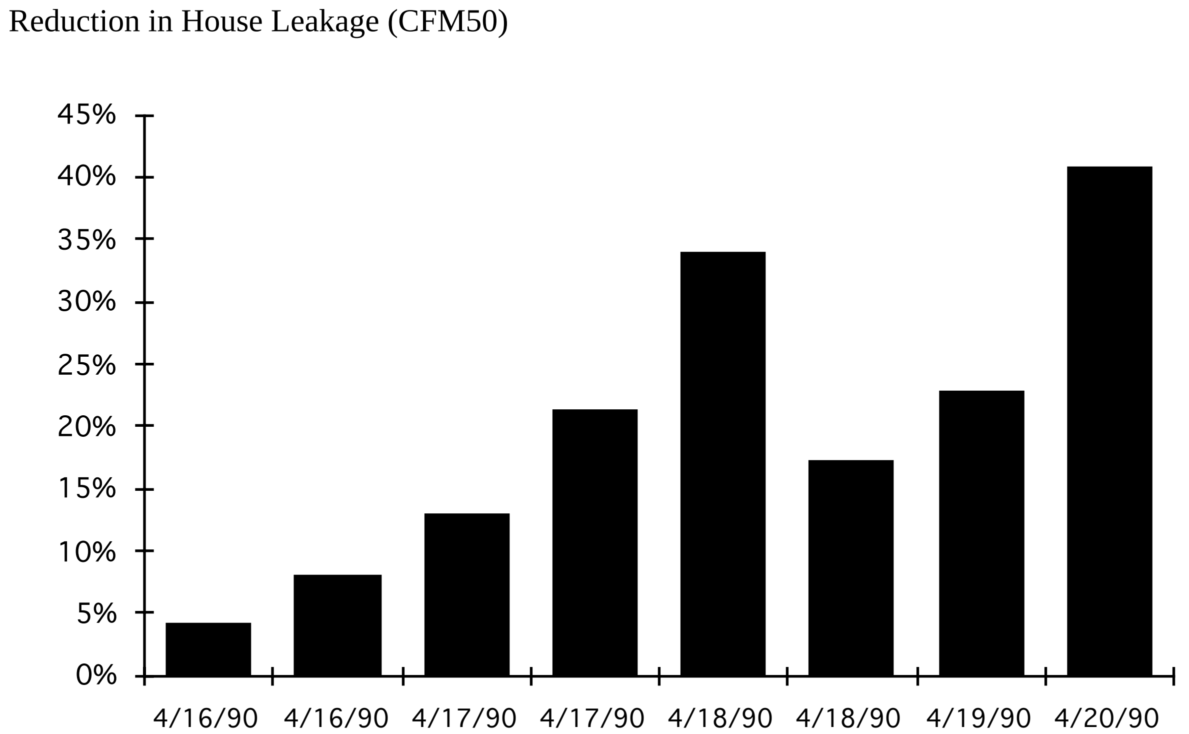


Figure 7. Learning Curve for House Medic

Table H. Effectiveness of House Medic Weatherization

Date	Initial Duct Leakage (cfm)	Final Duct Leakage (cfm)	Percent Reduction in Duct Leakage	Initial House Leakage (cfm)	Final House Leakage (cfm)	Percent Reduction in House Leakage
4/16/90	260	185	29%	2813	2691	4%
4/16/90	420	253	40%	5244	4817	8%
4/17/90	235	133	43%	2012	1752	13%
4/17/90	275	189	31%	4989	3918	21%
4/18/90	215	120	44%	1800	1189	34%
4/18/90	207	157	24%	3148	2606	17%
4/19/90	215	77	64%	2330	1797	23%
4/20/90	140	95	32%	2813	1661	41%

It is clear that specially-trained crews are necessary to apply the House Medic program. With training and supervision, the program should achieve its standards of 40% average reduction in air flow through the house (at 50 Pa) and duct leakage reduction of 65% (and below 150 cfm). The House Medic procedure has shown an average savings of 9.5% (Proctor, 1988). The 9.5% savings was achieved without duct sealing. When the duct sealing is included results indicate that a 15 to 20% savings will occur on houses of this type. The work can be performed by a crew of four in approximately four hours.

Ductwork

Duct leakage can be divided into catastrophic and diffuse leakage. Catastrophic leakage is the result of disconnected ducts and return systems open into the attic or crawl space. Catastrophic leaks can usually be spotted by anyone willing to crawl the length of the ducts and remove grilles. Thirty-one percent of the houses had catastrophic duct leaks. The pilot project utilized the heat pump technicians to find and repair these leaks.

Diffuse duct leakage is the sum of all the little leaks that occur at every joint and seam in the distribution system. While each of these leaks seems inconsequential in itself, the total represents a very substantial loss of heating and cooling energy. The average amount of leakage remaining after the catastrophic leaks were repaired by the heat pump technician was

249 cfm. (To put that into perspective, the average flow through the heat pumps was 1162 cfm.)

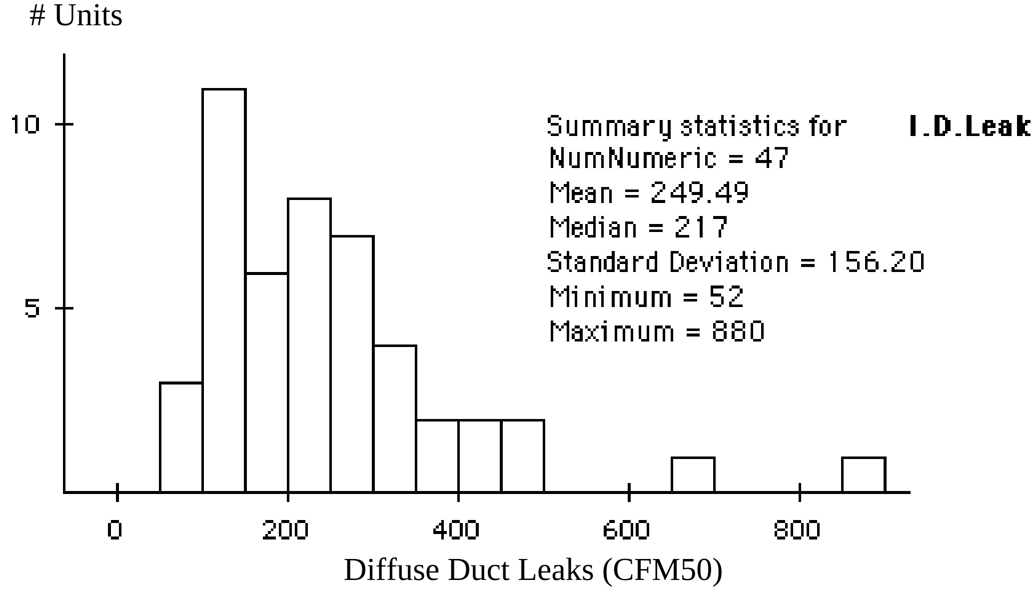


Figure 8. Histogram of Duct Leakage

Results from the flow hood duct leakage tests are shown in Figure 8. Even after the catastrophic duct leaks are fixed the diffuse leaks represent a major energy loss to the house.

The blower door tests demonstrate that diffuse duct leakage averages 7.7% of the total house leakage. This number is considerably smaller than the 18% that was found on a 40 house statewide sample by Berkeley Solar Group (1990), It is also smaller than the 17% found in Florida (Tooley, 1989). The 7.7% in the heat pump pilot project is for ductwork that has already been inspected by the heating technician and catastrophic duct leaks repaired. The importance of the remaining diffuse duct leakage is much larger than the 7.7% indicates. It is critical that equal size holes will produce substantially different heat loss depending on the pressure across the hole.

The highest pressure differential in the house occurs across ductwork cracks when the heat pump blower is on. Pressures of 50 pascals are common for 30% or more of the heating period. The estimated loss from diffuse duct leakage is shown in Table I.

Table I. Losses Due to Diffuse Duct Leakage
(average for study)

% of Total Infiltration (Blower Off)	8%
% of Total Infiltration (Blower On)	37%
% of Total Infiltration (Heating Season)	17%
Energy Loss from Duct Leaks	912 kWh/year

Ten houses were investigated to determine the difficulty and effectiveness of attempting to seal the diffuse leaks. The results in Table J exhibit the same pattern of learning as seen in the House Medic program. In the last houses the technicians began to achieve the levels of duct sealing desired.

Table J. Effectiveness of Diffuse Duct Sealing				
Date	**Initial Leakage (cfm)**	**Final leakage (cfm)**	**Sealed (percent)**	**Technician Hours**
2/21/90	182	172	5%	4
2/21/90	123	120	2%	4
2/21/90	198	136	31%	8
2/22/90	217	186	14%	4
2/22/90	286	246	14%	4
2/22/90	333	157	53%	8
2/23/90	404	255	37%	8
3/15/90	667	409	39%	8
3/16/90	211	22	90%	8
4/4/90	493	167	66%	6

This work indicates that with proper training and feedback it is possible for four hours of work on the ducts to achieve a 65% reduction in diffuse duct leakage. Work by Tooley (1990) in Florida produced an average reduction in duct leakage from 406 cfm to 136 cfm. The resulting cooling savings measured by Cummings (1990) was 18.8%.

Savings are estimated at 15% for catastrophic leaks and 7.5% for diffuse ones.

C. RESULTS OF SHORT TERM MONITORING PROGRAM

The three short term monitoring sites all obtained the same treatment. Each was monitored to establish the pre-test condition. After this baseline was established they were treated the same as the other units. All, however, were eventually treated for diffuse duct leakage. Throughout the process the data acquisition system reported on changes in use, patterns and temperatures.

Site 482

When the first trip was made to this unit it was discovered that the strip heat had never been wired into operation. The occupants burned kerosene most of the time in cold weather. The strip heat was wired in and they stopped using the kerosene heaters before the pretest period began.

SITE 482

In the pretest condition, this heat pump had:

- **Severely Restricted Airflow**
- **Inadequate Charge**
- **A Balance Point of 40°F**

The work completed on this unit included:

- **Improved Airflow**
- **Fixed Automatic Duct Dampers Open**
- **Recharged**
- **Installed a Outdoor Cutout on the Strip Heat**

The result was:

- **Measured Compressor Savings of 25%**
- **Monitored Increase in Heating Output for Same Input 25.3%**
- **No Net Reduction in Electrical Use**
  (due to house now heated and kerosene eliminated)

Figure 9 illustrates the pattern of usage during a typical day at site #482. Before the retrofit' At 6:11 AM the occupant raised the thermostat setpoint from 60°F to 71°F. This caused the heat pump to go into second stage heating—with both the compressor unit and the strip heaters operating. After 72 minutes of operation the strip heater turned off, and 15 minutes later the compressor did as well. At 4:53 PM a second manual thermostat adjustment produced a very similar pattern.

The percentage of warm up energy provided by strip heat for the morning and afternoon setups are 55.5% and 56.7%, respectively. The total percentage of the entire day's heating load provided by strip heat is 38.5% for this 53°F day.

Figure 9 also shows the heat pump operation at site #482 for a similar day after retrofit. No strip heat is used.

Comparison of Heat Pump Response: Site 482
Pre-retrofit (above) vs. Post-retrofit (below)

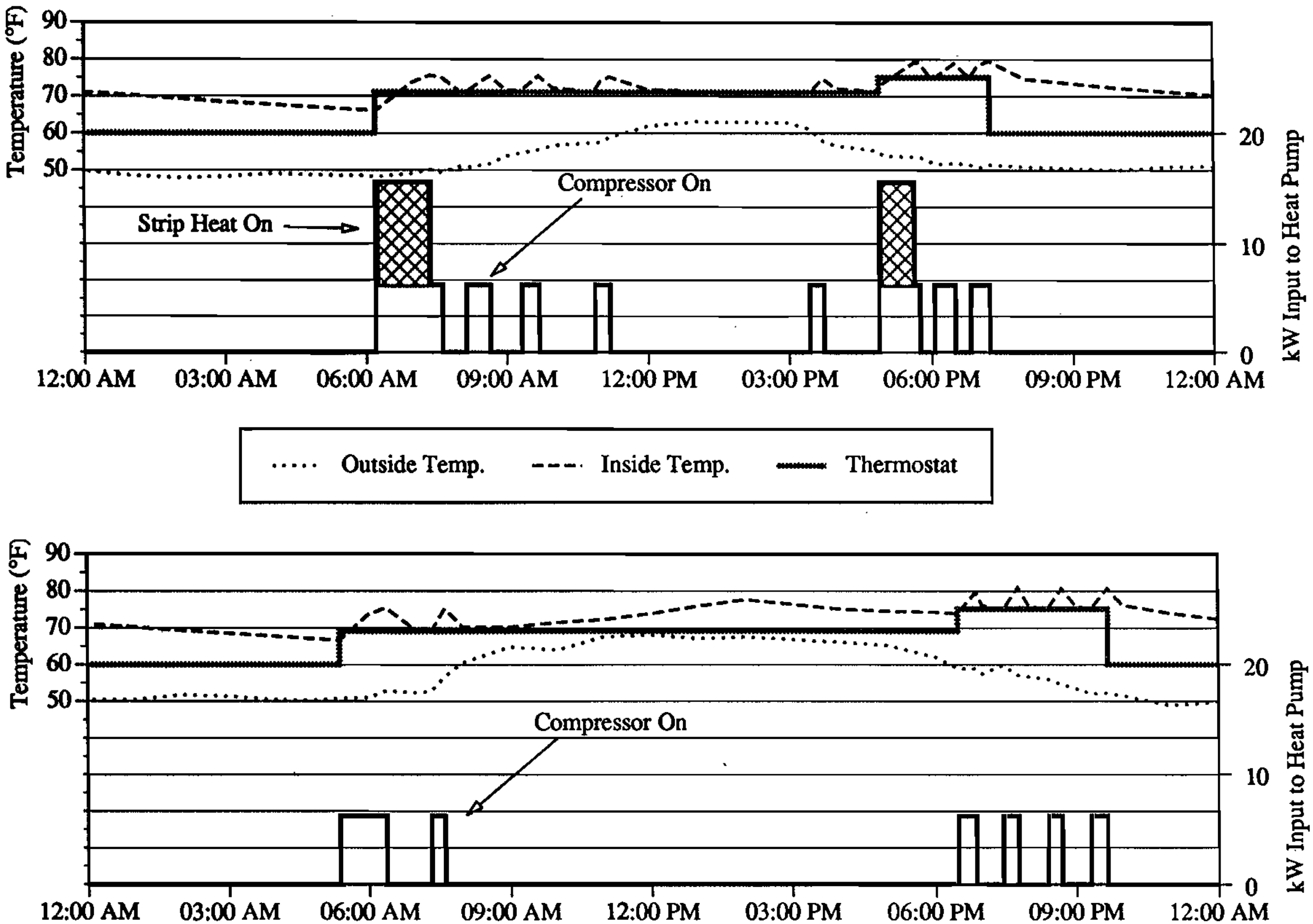


Figure 9

Site 154

It is often recommended that occupants turn up the temperature gradually to stay out of the heat strips and save money. The occupants of site #154 understood and practiced this. However, they fared almost no better than Site #482.

SITE 154

In the pretest condition, this heat pump had:

- **Restricted Airflow**
- **Inoperative Defrost**
- **A Balance Point of 30°F**

The work completed on this unit included:

- **Improved Airflow**
- **Repaired Defrost**
- **Installed a Digital Ramp up Thermostat**
- **Installed a Outdoor Cutout on the Strip Heat**

The result was:

- **Measured Compressor Savings of 11%**
- **Monitored Energy Savings 12.2%**

Figure 10 shows before the retrofit, between 7:16 and 10:33 AM the occupants gradually adjusted their thermostat five times to raise the setpoint from 50°F to 65°F. Even with this care the strip heaters operated at each adjustment.

The percentage of warm up energy provided by strip heat for the morning setup is 48% . The total percentage of the entire day's heating load provided by strip heat is 27% for this 42°F day.

Figure 10 also shows the heat pump operation at site #154 for a similar day after the retrofit. No strip heat is used.

Comparison of Heat Pump Response: Site 154
Pre-retrofit (above) vs. Post-retrofit (below)

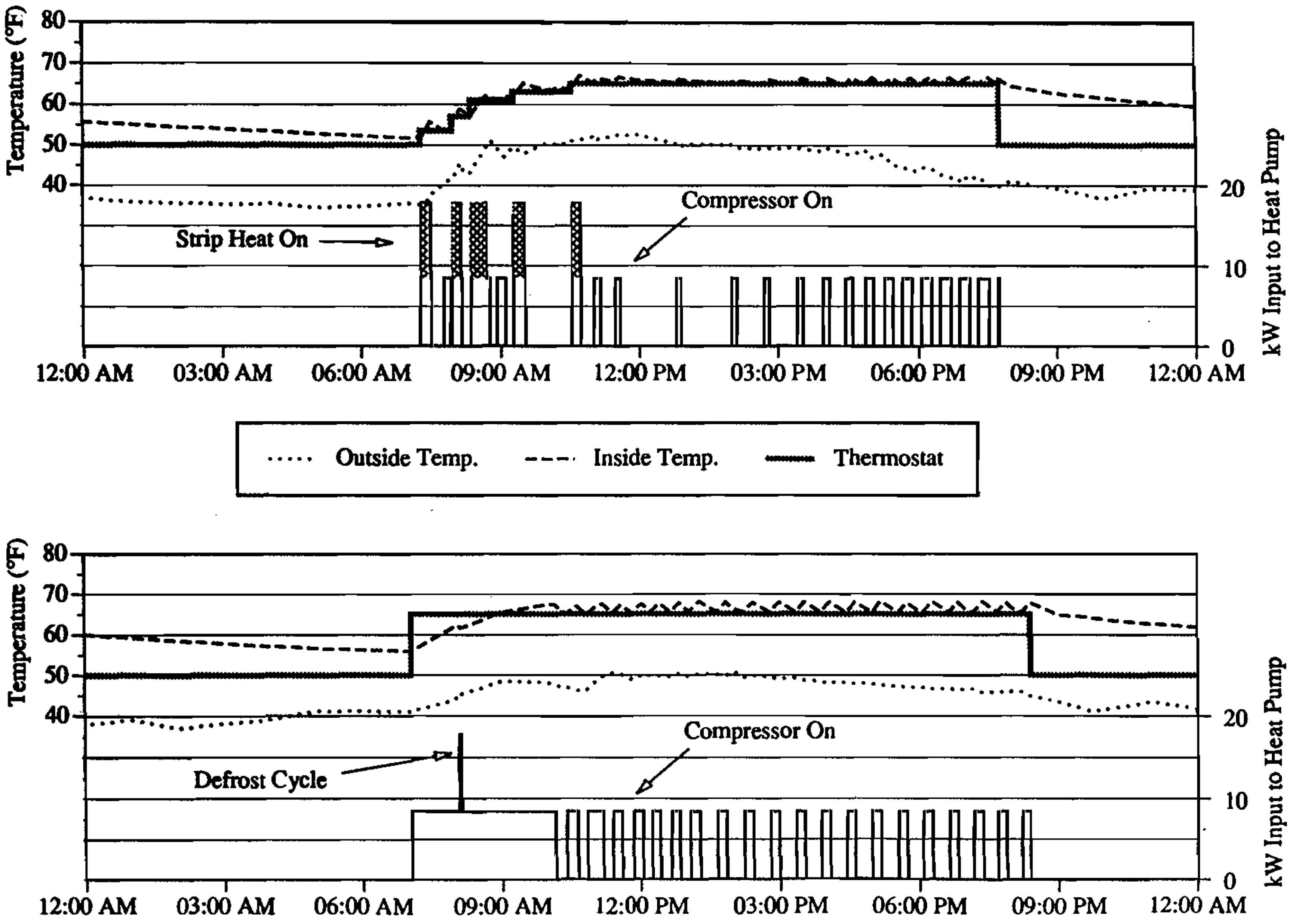


Figure 10

Site 366

This unit used very little setback, but still used strip heat.

SITE 366

In the pretest condition, this heat pump had:

- **Strip Heat Wired to Compressor Stage**
- **Refrigerant Leak**
- **Inadequate Charge**

The work completed on this unit included:

- **Rewired Strip Heat to Stage Two Only**
- **Repaired Leak**
- **Installed Correct Charge**
- **Installed a Digital Ramp up Thermostat**
- **Installed a Outdoor Cutout on the Strip Heat**

The result was:

- **A Balance Point of 34°F**
- **Measured Compressor Savings of 62%**
- **Monitored Energy Savings of 44.2%**

Figure 11 shows the heat pump operation at site #366. Before the retrofit, 40 amps of strip heat were wired to the first stage heating. The system operated with many short cycles, usually less than 5 minutes long. The occupants had a small child and usually kept the indoor temperature constant during the night and set back the temperature during the day when everyone was at work. The evening setup would cause the addition of 20 amps of strip heat to operate as second stage heat. After retrofit the building is heated with longer cycles of compressor operation and without strip heat.

Comparison of Heat Pump Response: Site 366
Pre-retrofit (above) vs. Post-retrofit (below)

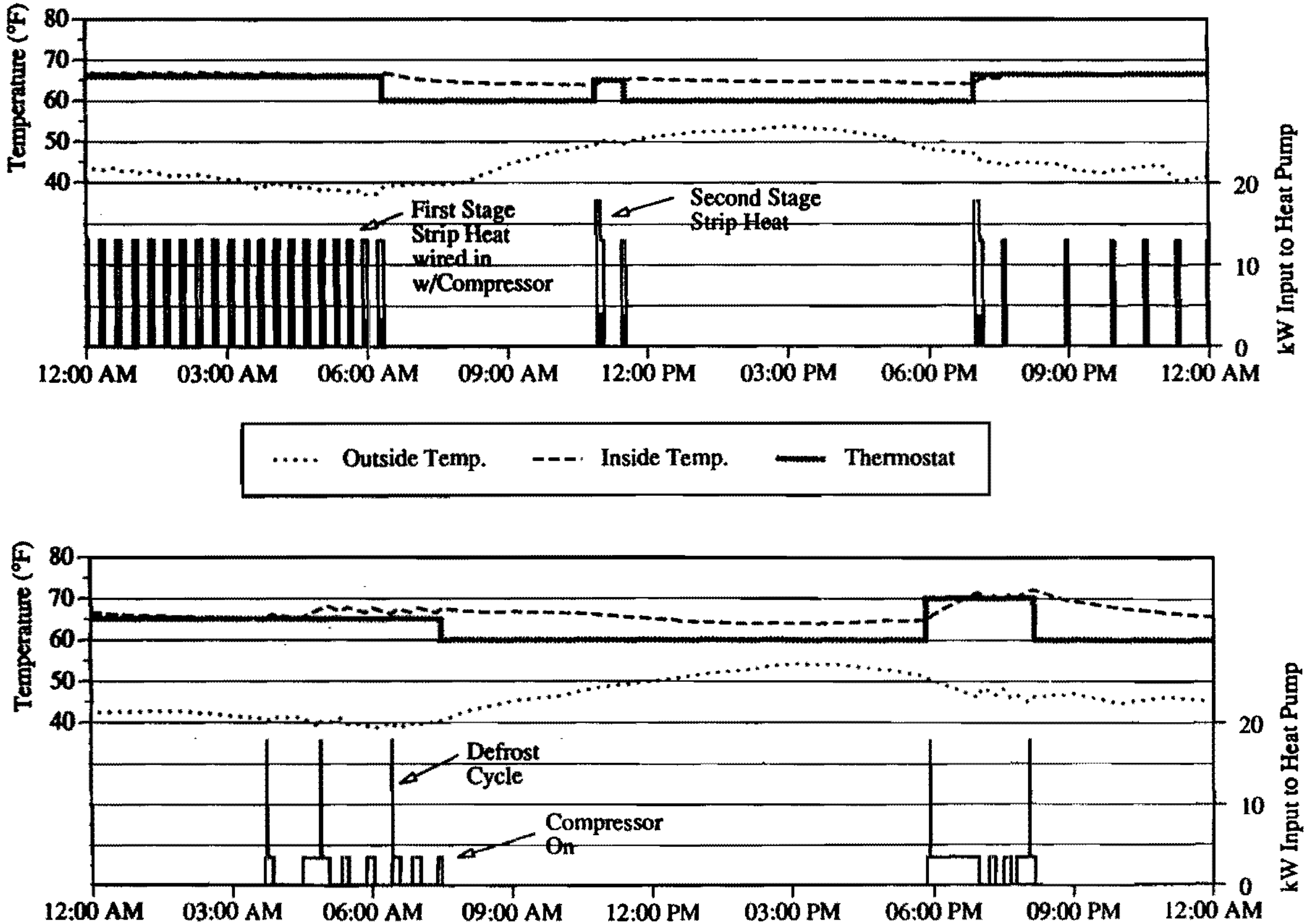


Figure 11

Thermostat Control and Strip Heat Use

The majority of strip heat use occurred because of manual adjustment of the thermostat by the occupant. The use of strip heat when the outside temperature was below the balance temperature was almost nil. Consequently even though how a person adjusts the thermostat has little influence on strip heat use, strip heat use is highly interconnected with if a person adjusts the thermostat

Estimate of Energy Savings Due to Outdoor Cutout Control

In order to predict the savings from the use of an outdoor cutout an energy use model was constructed. The model uses parameters measured in the field monitoring including: load (kW/°F), cooldown time constant (hours), thermal mass (kWh/°F) and average solar gain (kW), In addition the operation of the defrost, compressor and strip heat were determined. The model relies on actual field parameters thus minimizing potentially inaccurate assumptions.

Weather data was obtained from BSG Software. The hourly data file was used to simulate building performance in Grass Valley, CA. (The actual data is 1962 data from Sacramento which was been mathematically modified to correspond to Grass Valley.)

The daily heat pump operation was divided into four segments: Day, Cooldown, Night, and Warmup. The Day and Night segments are constant indoor temperature operations with the heat pump just supplying the load each hour. During the cooldown segment no energy is used by the heat pump and the building temperature drifts down. The Warmup period occurs when the thermostat setting is again raised. It is during the Warmup period that the majority of unnecessary strip heat operation occurs.

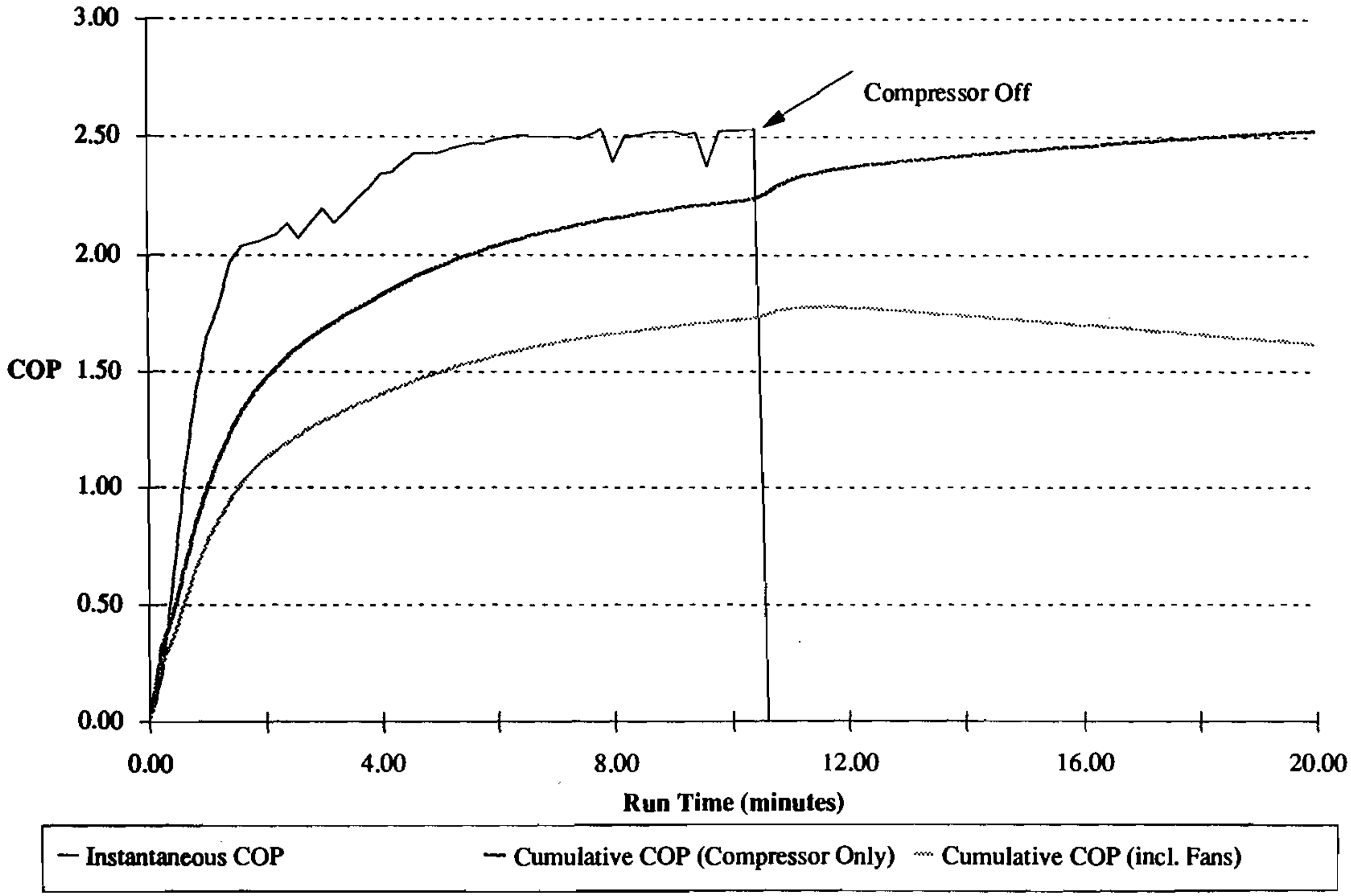
Table K. demonstrates the savings from various cutout settings.

Table K. Effect of Strip Heat Cutout					
Cutout Temp.	**Defrost kWh seasonal**	**Strip kWh seasonal**	**Compressor kWh seasonal**	**TOTAL kWh seasonal**	**Energy Savings**
w/o	36.1	4364.2	3964.2	8364.5	base case
35 °F	45.2	1008.3	5199.2	6252.7	25.25%
40 °F	41.6	2229	4720.3	6990.9	16.42%
45 °F	39	3184.5	4368.3	7591.8	9.24%

Heat Pump Operation—Run Time vs. COP

Figure 12 provides a detailed description of the operation of the heat pump during a cycle, and illustrates the effect of run time on COP. This data was obtained with the 12 second scan attended mode at site #366. The cumulative COP for the full cycle is significantly reduced with cycles less than 4 minutes in length.

The data was collected with the indoor fan continuously running. By running the indoor fan after the compressor has turned off, additional heat can be obtained from the warm indoor coil. This will raise the effective cycle COP. The optimal fan off delay is between two and three minutes, which raises the full cycle COP by about 4 percent.



Compressor Off
3.00
2.50
2.00
COP 1.50
1.00
0.50
0.00
0.00
4.00
8.00
12.00
16.00
20.00
Run Time (minutes)
Instantaneous COP
Cumulative COP (Compressor Only)
Cumulative COP (incl. Fans)

Figure 12

Comparison of the Operation of Various Thermostats

At two of the sites, #154 and #366, the original two-stage mercury bulb thermostat was replaced with an electronic digital model. At site #154 this increased the temperature differential (the difference between the on and off temperature) by 1°F. The longer cycle is more efficient as long as significant overheating does not occur. In most respects, the electronic thermostat operated similarly to the manual one which it replaced.

D. SUMMARY OF ENERGY SAVINGS ESTIMATES AND COSTS

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

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 fifty houses in the sample is then averaged producing an unweighted average savings for the program.

Overall Savings, Cost and Benefits

Table L shows the projected energy savings, costs, and net lifecycle benefit for the program. Interactive effects are included.

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

Average Heating Energy Savings	27%
Average Cooling Energy Savings	22%
Utility Cost	$400
Utility Net Lifecycle Benefit	$459
Participant Cost	$50 to $350
Participant Net Lifecycle Benefit	$2,597

Projected energy savings are shown in Table M for the pilot field work. Pilot work did not include repairing restrictive ductwork. Diffuse air leakage was treated on only ten houses. The fan time delay and the more accurate outdoor cutout control were not included.

Table M Pilot Field Work Savings (including interactions)

Average Heating Energy Savings	**18.9%**
Average Cooling Energy Savings	**15%**

<u>Itemized Savings, Costs and Benefits</u>

In order to plan the mix of measures included in the program it is necessary to look at the individual cost, savings, and benefits. Table N indicates the heating energy savings for individual retrofit measures, taken separately (excluding any interactive effects). Also shown are estimated labor and materials costs and the calculated net lifecycle benefit.

Table N also exhibits the heating energy savings for the optional “House Medic” super weatherization modifications as a stand alone program, and without ductwork (as if it were to follow the designed program). It would be feasible to use the non-duct portion of House Medic on houses that were identified as leaky while the initial duct testing was done. These modifications are more cost effective than traditional caulk and weatherstrip programs.

Table N. Heating Energy Savings and Cost Estimates for Individual Retrofit Measures

Retrofit Measure	Average Heating Energy Savings	Est. Cost per Site	Percent Utility Contribu-tion	Net Owner Lifecycle Benefit	Net Utility Lifecycle Benefit
Duct and House Diagnostics		$60	100%		
Heat Pump Diagnostics		$30	100%		
Repair Disconnected Ducts	15.0%	$35	100%	$1,638	$562
Repair Diffuse Duct Leaks	7.5%	$150	100%	$952	$147
Install Thermostat Cutout	10.0%	$100	25%	$462	$82
Correct Low Air Flow	5.6%	$50	50%	$312	$52
Install Fan Off Time Delay	3.6%	$50	50%	$167	$23
Repair Leaks and Correct Refrigerant Charge (approx. 30% of units)	18.4%	$200	25%	$777	$215
House Medic (alone)	15%	$530	25%	$1,281	$470
House Medic (after duct repairs are already done)	7.5%	$430	25%	$612	$194

Cost-Benefit Analysis

The net lifecycle benefit would change substantially with climate and use patterns. In this case the kWh saved in both the heating mode and the cooling mode is substantially leveraged because these houses are high energy users.

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

The cost estimates contained in the tables are based on the following:

- Initial visit labor at $30 per hour to do non-intrusive heat pump tests, duct leakage tests and duct repair.
- Follow up visit labor by a trained heating technician at $50 per hour to wire, clean the coil, repair refrigerant leaks and recharge.
- Materials at volume discounts for the parts used on most units—cutouts etc.
- Special materials for individual heat pumps, at retail cost.
- Time estimates for the heating technicians based on the speed of the technicians at the end of the pilot.
- Time estimates for the initial test and duct technicians based on experience with trained furnace inspector/repair technicians.
- Per unit training and administrative costs are not included and are very dependent on the scale of the program.

IV. Conclusions

Energy Cost Inquiries (ECI) for the houses evaluated in this project were caused by identifiable problems with the heat pump, the heat pump controls, the ductwork, or the building shell.

All of the houses studied (with the exception of one that did not meet the original selection criteria) had at least one major problem with these systems.

For every ECI there are a number of other houses with the same problem.

Most participants knew of neighbors that had similar complaints about their heat pumps. Many knew of someone who had switched heating fuels.

"Typical" heat pump technician check-ups do not find nor solve the problems.

Nearly every participant had tried to discover the source of the problem by calling a heating contractor. In most cases the effort was in vain. At times the technician had actually done damage. When faced with a situation that they cannot fix it is common for the technician to blame the problem on the heat pump.

These problems can be resolved when the technicians are trained and follow fixed procedures for diagnosis, repair and verification.

The savings for the work done during the pilot met the initial savings goal for the program. The solutions tested in the field were successful in resolving a majority of the problems.

Try as they might, most homeowners cannot "sneak up the heat" slow enough to stay out of strip heat.

The monitored location that religiously attempted this procedure still provided 48% of their warm up energy with strip heat.

V. Recommendations

These recommendations are grouped by scope of application, program design, program economics, evaluation and implications for new and replacement heat pump incentive programs.

Scope

1) The program should be proactive, seeking out customers with potential problems rather than just reacting to those who complain. Many of the potential participants in the pilot problem had already reached a point where they were no longer willing to cooperate with the utility. A proactive approach would reach those customers and increase goodwill before it is lost. The best efforts should be made to provide the service to customers that meet a utility use profile indicating their need. In a proactive program the customers may see the utility as an ally in controlling their energy use, rather than the cause of their high energy bills. A proactive program will have the opportunity to solve the problems of individuals who will never call to complain, but will just switch heating fuels. Proactive involvement allows the local PG&E personnel to operate from a more personal position of caring, than waiting for irate customers to call.
2) Investigate the system for use on residential air conditioning systems.
3) Investigate the applicability of this system for average heating use heat pump customers.

Program Design

1) Use the least costly method of delivering the services. Utilize well-trained, technicians to obtain the initial data and repair the most common problems. At the time of the initial visit, duct repair work should be performed to bring the total duct leakage down to less than 150 cfm, and to eliminate flow restrictions. The final airflow and COP of the unit should be tested to determine if additional efficiency work, such as repairing refrigerant leaks, correcting charge, and cleaning the indoor coil is needed. The final duct test will include a whole house measurement.

   The initial visit should be done by two specially trained individuals with all the necessary materials to do substantial duct repair. This alone will solve almost half of the low airflow problems, repair 100% of the disconnected ducts, and significantly reduce the diffuse duct leakage problems.
2) Utilize the higher cost skilled heating technicians on a fixed cost basis and only to accomplish the standard elements and repairs identified at the first visit. Every home should have a visit by a specially-trained heat pump technician. The

minimum visit will include installation of an accurate outdoor cutout thermostat on the heat strips and a relay to delay the fan off time. Other work, including cleaning the indoor coil, checking and resetting charge, and refrigerant leak repair should be done on a fixed cost basis, with a portion of the cost rebated by PG&E.

3) Utilize a program manager responsible for the quality of the program. This individual reviews the reports from the initial visit and determines follow-up work to be done. Essential elements in the system include rapid written and verbal feedback to the technicians and inspection of sample units. Controls must include suspension of contractors from the program when they fail to meet the technical, logistical or customer interaction requirements.

4) Utilize multiple subcontractors in each area to insure that deviations from the program can be corrected.

5) The initial contractor should schedule the site visit. All the logistics of providing materials, transportation, etc. must be his/her responsibility. The allowable percentage of reschedules, missed appointments and completion dates should all be set by the program.

6) Consider offering additional services such as major weatherization, extensive heat pump repair etc. on a fixed cost, reduced incentive to the customer.

Program Economics

Achieve maximum cost-effective energy savings for each site by combining PG&E subsidies with customer contributions. The ideal customer contribution would achieve highest energy savings at the lowest possible utility cost. It is likely that this would result in PG&E offering the the initial visit that accomplishes the most cost effective items free or nearly free. This would overcome suspicion, obtain maximum participation and get these measures completed. A lesser incentive could be offered for subsequent and less cost effective items.

Evaluation

Complete a long term before and after utility bill analysis on the homes. In the absence of evaluation, any program cannot be guaranteed to produce its potential savings.

New and Replacement Heat Pump Efficiency Programs

If incentives are considered for new heat pump installations, these installations should be held to strict criteria. The only insurance that the installations are installed properly is a test of the unit and its ductwork. Criteria for acceptance might be:

- The measured air flow is between 5% below and 15% above the manufacturer’s specification.

- The installed EER or COP is tested on site and is within 5% of the manufacturer's specification.
- The duct leakage is tested and is less than 150 cfm at 50 Pa house pressure.
- The ductwork is sealed at every joint with mastic.
- The coil and filters are accessible and easily serviced.
- An outdoor cutout control is installed.

Major Weatherization Programs

House Medic should be evaluated against actual measured savings from other weatherization options. It should be tested on a larger scale with adequate crew training.

Appendices

Appendix A - Annotated References and Bibliography

Appendix B - Customer Information Form

Appendix C - Efficiency Improvement Procedure Form

Appendix D - Duct Repair Procedure Form

Appendix E - Inspection Form

Appendix F - House Data

Appendix G - Equipment and Materials

Appendix H - Energy Savings Calculations

Appendix I - Air Changes and Duct Leakage

Appendix J - Implementation Plan

Appendix K - Training Plan

Appendix L - Procedure Manual

Appendix A

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Appendix B

Customer Service Report

Heat Pump Service Visit Customer Report

PG&E's Residential Heat Pump Efficiency Project is a service for PG&E customers with electric heat pumps as a primary heat source. The purpose of this service is to provide our customers with the most efficient electric heat available.

The services marked below were performed on your heat pump system. A short explanation of how your heat pump works may help you understand the benefits from the service as well as prepare you for any changes in the system's operation .

One key to lower heating bills is to use the compressor system to provide as much of the buildings heat as possible and to <u>only</u> use the electric resistance when absolutely necessary. In this way the compressor's greater efficiency will save you the most money. The technician has provided you with our brochure <u>How to Live With Your Heat Pump,</u> it will provide you with a thorough description of how the heat pump works.

1)______ A new electronic programmable thermostat has been installed at your home. The thermostat allows you to automatically change the temperature settings in your home for active/occupied, and sleeping/unoccupied periods. You can save money by programming your thermostat to a lower setting while away from home or asleep. The thermostat will automatically use the least expensive amount of heat to warm the residences when switching temperatures.

2)______ An outdoor cutout was installed on your heat pump. The cutout prevents the less efficient electric resistance heaters from operating when the weather is warm enough that the compressor system can adequately heat the house.

3)______ The strip heaters on your heat pump were wired to first stage heating. They will still operate when necessary with second stage heat. YOU MAY NOTICE that the air coming from the air supply registers is cooler. This is normal for the more efficient compressor heating cycle.

4)______ A refrigerant leak has been fixed and the unit has been recharged. The unit should not need to be recharged again. YOU MAY NOTICE that the air delivery is warmer and the house heats more quickly.

Appendix C

Heat Pump Procedure Form

5)______ The inside coil of the heat pump was cleaned. This increases the air flow and allows more heat to be delivered, resulting in increased efficiency. You may notice that the supply air temperature is cooler because of the increased flow, however, at the lower temperature a greater quantity of heat is now being delivered because of the increased air flow..

6)______ The ducting has been repaired and sealed. This prevents heated air from escaping into or entering from unheated areas.

7)______ A washable filter and whistle was added. Every month the filter needs to be cleaned. You can vacuum the filter clean, but at least once a year you should clean it with water. Use your hose. If the whistle starts whistling, you should have cleaned your filter months ago. A clean filter allows air through the heat pump. No air means very little heat and very high bills.

The service work performed today comes with a one year warranty. If you experience difficulties, please call:

Dial One
Raymond's Heating and Cooing
916/823-0114

your service person is ____________________ __________
Date

FORM HP

HEAT PUMP 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 a woodstove ?________ Fireplace? ______ How many fires a week?____________

Number of occupants:	Adults	Teenagers	Children

Technician______________ Date __________

1. INITIAL INTERVIEW:

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 heat pump? ________yrs.

Have you had a visit by a heat pump service technician to check your heat pump?_____
When?__________ Who? ____________________________
What Did they do?____________________________

Who manages the thermostat?______________ Does anyone else in the house manage it differently? ______________ How?____________

Do you "set back" your thermostat at night or when you are away from home each day?______
Approx. 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 Heat Pump?________ If yes could you get it for me now?

Check and record indoor temperature __________

HEAT PUMP INSIDE UNIT FAMILIARIZATION & PREPARATION

2. Record from nameplate: Manufacturer ________ Model ____________

3. Duct Location______________________________

4. Install digital thermometer to measure delivery and return temperatures. **THIS MUST BE SOMEWHAT DISTANT FROM THE HEAT STRIPS.**

5. Install amp-clamp to measure current to the heat strips.

THERMOSTAT INFORMATION AND FIRST CYCLE **PREREAD**

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

7. Thermostat Type: Single Stage ___ Two Stage______ Programable HP ______

8. Check thermostat: Setting ____°F Set back _____ from____ to ____, is clock ok?_____ anticipator settings #1_____#2______

9. Start heat pump by activating ONLY the first stage with thermostat. Check and record if there is current to the strip heaters. __________ If furnace doesn't turn on, **STOP! Contact Supervisor and tell Client.**

10. Set the thermostat down. **FROM THIS POINT ON THE HEAT PUMP CAN BE CONTROLLED AT THE THERMOSTAT OR AT THE TERMINAL BLOCK.** The next test will be on emergency heat (heat strips) only.

HEAT PUMP OUTSIDE UNIT FAMILIARIZATION & PREPARATION

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

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

13. If the homeowner reports that a service technician recently put added to the charge, check for leaks now.

14. Record from nameplate: Manufacturer _________ Model _____________

15. Look up the rated heating delivery ______ and EER __________

16. Convert heating delivery to tons (btu)____/12,000 = ______ Tons

17. Locate where you will read the voltage to the compressor.

18. Locate where you will put the amp-clamp to measure current to the compressor.

INITIAL OPERATION - AIR FLOW TEST **PREREAD**

NOTE THAT THESE TWO TESTS ARE TIMED - IT IS ESSENTIAL THAT THE READINGS BE TAKEN AT THE TIME SPECIFIED.

19. Start the heat pump in the emergency heat mode and start your watch to measure times.

20. At EXACTLY 5 minutes record the first return temperature ______

21. Measure and record the Amps on both legs _____/_____ and Volts_______to the heat strips. Remove the amp-clamp and voltmeter. Prepare to take them to the outside unit

22. At EXACTLY 10 minutes record the supply temp ______ then the return temp ____ Disable the heat strips. Remove your amp-clamp and volt meter and take to compressor.

EFFICIENCY AND OVERCHARGE TESTS PREREAD

23. Switch to compressor only heating and restart your stop watch.
24. Install the amp-clamp to measure the compressor current.
25. At EXACTLY 5 minutes record the supply temp ______ then the return temp ____
26. At EXACTLY 7 minutes measure and record the Amps on both legs ____/____to the compressor.
27. Record the Watts from the watt meter ______ or Watts from house meter test.______
28. Measure and record the Volts________to the compressor.
29. Record the outdoor air temperature from the outside thermometer________

ACID AND MOISTURE TESTS

30. Perform the Carrier "TOTAL TEST" and record the results ______ Acid, ______ Moisture.

CALCULATIONS

31. AIR FLOW

Strip Heater ________Amps. X ________ Volts = ________ Watts

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.

32. OUTPUT

(________ Strip Watts / ________ Δ T Strip) X ________ Δ T Comp. = ________ Watts

33. APPARENT INPUT

Compressor ________Amps. X ________ Volts = ________ Watts

34. ACTUAL INPUT

Watts from house or portable watt meter ________ Watts

35. COEFFICIENT OF PERFORMANCE

________ OUTPUT / ________ ACTUAL INPUT = ____ C.O.P.

Result is plotted on the COP Graph. It should be above the minimum line for a heat pump with the same EER rating or EER 7.8. If it is less, we must find if the unit is under or over charged. Use the manufacturers method for determining correct charge if it is available otherwise adjust charge to maximum COP, while checking your head and suction pressures.

REPAIRS AND ADJUSTMENTS

36. Are there any refrigerant leaks? If so repair, evacuate and recharge with the precise charge. Record location of all leaks____________________

37. If there is moisture or acid in the system, Inform the homeowner, Evacuate and purge the system, saving the refrigerant for recycling. Then recharge with the precise charge.

38. If COP is less than specified on COP graph, determine if unit is under or overcharged and charge to correct charge.

39. If AIRFLOW is less than 400 cfm. remove restrictions and increase blower speed to achieve over 400 cfm. Record all work done____________________

40. Visually inspect evaporator coil record cleanliness and clean. ________________.

41. Inspect filter and record condition. __________ Clean or replace the filter

42. Visually inspect blower record cleanliness and clean if dirty ________________.

43. Oil circulation blower and motor.____________________

44. If Defrost cycle has an initiation timer and it is adjustable and it is set at less than 90 minutes reset it to 90 minutes and record____________________

DUCTWORK

45. 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 ____________________

46. 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 ____________________

47. Visually inspect all the ductwork by walking/crawling the length of it. Repair any disconnects or substantial leaks. ____________________

CONTROLS

48. Unless the thermostat is a programable heat pump thermostat with a built in ramp up feature install a new HP thermostat and record____________________
    <u>Check out the function of your installation.</u>

49. Install an outdoor thermostat to cut out the strip heaters when the temperature is above 35°F. Be sure the probe is sensing the outdoor temperature and will not be in the sunlight. The cut out should not effect the control of emergency heat. Record all work done________________
    <u>Check out the function of your installation.</u>

FINAL TESTS - AIR FLOW TEST PREREAD

NOTE THAT THESE TWO TESTS ARE TIMED - IT IS ESSENTIAL THAT THE READINGS BE TAKEN AT THE TIME SPECIFIED. ALWAYS PERFORM THIS TEST UNLESS NO DUCT SEALING, COIL, FILTER OR BLOWER CLEANING HAS BEEN DONE

50. Reconnect the strip heaters. Start the heat pump in the emergency heat mode and start your watch to measure times.

51. At EXACTLY 1 minute record the first return temperature ______

52. At EXACTLY 5 minutes record the heat rise ______

53. At EXACTLY 5 minutes and 15 seconds record the second return temperature ______
Disable the heat strips.

FINAL EFFICIENCY AND OVERCHARGE TESTS PREREAD

54. Switch to compressor only heating and restart your stop watch.

55. Install the amp-clamp to measure the compressor current.

56. At EXACTLY 5 minutes record the heat rise ______

57. At EXACTLY 7 minutes measure and record the Amps on both legs ____/____to the compressor.

58. Record the Watts from the watt meter _____ or Watts from house meter test._____

59. Measure and record the Volts_______to the compressor.

60. Record the outdoor air temperature from the outside thermometer_______

FINAL CALCULATIONS

61. AIR FLOW

Air Flow (_______ Strip Watts / _____ Δ T) X 3.16 = ________ CFM

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

62. OUTPUT

(_______ Strip Watts / ________ Δ T Strip) X ________Δ T Comp. = ________ Watts

63. APPARENT INPUT

Compressor _______Amps. X ________ Volts = _______ Watts

64. ACTUAL INPUT

Watts from house or portable watt meter ________ Watts

65. COEFFICIENT OF PERFORMANCE

________ OUTPUT / ________ ACTUAL INPUT = _ C.O.P.

Result is plotted on the same COP Graph as used earlier. Use this to explain to the homeowner what you have accomplished.

WORK DONE ON COMPRESSOR UNIT AND EFFECT PREREAD

Work Done____

____

____

____

____

____

____

____

____

____

____

____

EFFICIENCY AND OVERCHARGE TESTS PREREAD

66. REDO AIR FLOW TEST if you have changed the airflow and record results below.
67. Start compressor only heating and restart your stop watch.
68. Install the amp-clamp to measure the compressor current.
69. At EXACTLY 5 minutes record the heat rise _______
70. At EXACTLY 5 minutes record the supply temp _______ then the return temp ____
71. At EXACTLY 7 minutes measure and record the Amps on both legs ____/____to the compressor.
72. Record the Watts from the watt meter ______ or Watts from house meter test.______
73. Measure and record the Volts________to the compressor.
74. Record the outdoor air temperature from the outside thermometer_______

CALCULATIONS

75. AIR FLOW

Air Flow (________ Strip Watts / ______ Δ T) X 3.16 = _________ CFM

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

76. OUTPUT

(_______ Strip Watts / ________ Δ T Strip) X ________Δ T Comp. = _________ Watts

77. APPARENT INPUT

Compressor _______Amps. X ________ Volts = _______ Watts

78. ACTUAL INPUT Watts from house or portable watt meter ________ Watts

79. COEFFICIENT OF PERFORMANCE

_________OUTPUT / _________ ACTUAL INPUT = _ C.O.P.

Appendix D

Duct Repair Procedure Forms

DUCT WORK FORM

DUCT WORK INFORMATION Homeowner ______________________

Address ______________________ City ______________________

Zip Code __________ Home Phone ______________ Work Phone __________

Inspector ______________ Date ______

Are there any portions of the house that either get too much or too little heat?__________

____

____

____

Check and record indoor temperature __________

INITIAL BLOWER DOOR TEST

1. Install the blower door to pressurize the house.
2. Close all windows and exterior doors. Be sure to close fireplace and wood stove dampers.
3. Do the first three blower door tests. Have the homeowner help you find all the registers.
4. Check and record all the data on the Duct Leakage Test Form. This includes a guess at the wind speed, and the number of inches of insulation in the walls, ceiling and floor.. Sheilding factor is normally 1.0, If the house is exposed without trees it is 1.2, If it is behind other buildings it is .9.

DUCT WORK FAMILIARIZATION & PREPARATION

5. Duct Location______________________________________
6. Is ductwork rigid or flex? ______________________ Is duct work insulated?______
7. AS YOU PROCEED RECORD ANY UNUSUAL RESTRICTIONS OR DISCONNECTS OF THE DUCT WORK.______________________________________

____

____

____

DUCT SEALING AND RESTRICTION REMOVAL

8. Remove all fiberglass wrap from joints.
9. Seal the joints.
10. Reinsulate the joints.
11. If flex duct use the duct ties to eliminate leakage.

FINAL TEST

12. Do the final blower door test. If leakage is not less than 50 CFM, find and repair the leaks.

92.015

LEAKAGE TEST

CLIENT	____________	Date	______
Stories (1-3)	____________	Inside °F	______
Wind? (0-30)	____________	Outside°F	______
Floor R Value	____________	Ceiling R	______
Wall R Value	____________		______
Shielding(.9-1.2)	____________	Inspector	______

Test #1

House Pressurized - vents open

House pa.	Fan pa.	Plate/Holes plugged

Test #2

House Pressurized - vents closed

House pa.	Fan pa.	Plate/Holes plugged

Test #3

House Pressurized - one vent open

House pa.	Flow Hood Reading

Final Test (#4)

House Pressurized - one vent open

House pa.	Flow Hood Reading

BE SURE TO PUT THE BUILDING PLAN ON BACK

DONT FORGET TO NOTE AVERAGE CEILING HEIGHT

Appendix E

Inspection Form

HP INSPECTION FORM

HEAT PUMP INSPECTION Homeowner ____________________

Address ____________________ City ____________________

Zip Code __________ Home Phone ______________ Work Phone __________

Inspector ______________ Date ______

Have you noticed any changes since the technician was here?______________________

____

____

____

____

What did the technician do?______________________

Did they explain how to manage the thermostat and how to be sure you don't use the heat strips?______________________

Check and record indoor temperature __________

HEAT PUMP INSIDE UNIT FAMILIARIZATION & PREPARATION

1. Install digital thermometer to measure delivery and return temperatures. **THIS MUST BE SOMEWHAT DISTANT FROM THE HEAT STRIPS. Put where the technician put theirs if it is appropriate. If the location was wrong record why.**______________________

2. Install amp-clamp to measure current to the heat strips.

HEAT PUMP OUTSIDE UNIT FAMILIARIZATION & PREPARATION

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

4. Is the unit installed in a location that will cause air to recirculate through the outside coil?___ If so record what the cause is. Take Pictures ______________________

5. Locate where you will read the voltage to the compressor.

6. Locate where you will put the amp-clamp to measure current to the compressor.

7. Install the watt meter if you have it.

OPERATION - AIR FLOW TEST PREREAD

NOTE THAT THESE TWO TESTS ARE TIMED - IT IS ESSENTIAL THAT THE READINGS BE TAKEN AT THE TIME SPECIFIED.

8. Start the heat pump in the emergency heat mode and start your watch to measure times.

9. At EXACTLY 5 minutes record the first return temperature ______

10. Measure and record the Amps on both legs _____/______ and Volts_______to the heat strips. Remove the amp-clamp and voltmeter. Prepare to take them to the outside unit

11. At EXACTLY 10 minutes record the supply temp _______ then the return temp ____ Disable the heat strips. Remove your amp-clamp and volt meter and take to compressor.

EFFICIENCY AND OVERCHARGE TESTS PREREAD

12. Switch to compressor heating only and restart your stop watch.

13. Install the amp-clamp to measure the compressor current.

14. At EXACTLY 5 minutes record the supply temp _______ then the return temp ____

15. At EXACTLY 7 minutes measure and record the Amps on both legs ____/____ to the compressor.

16. Record the Watts from the watt meter ______ or Watts from house meter test.______

17. Measure and record the Volts________ to the compressor.

18. Record the outdoor air temperature from the outside thermometer________

CALCULATIONS

19. AIR FLOW

Strip Heater ________ Amps. X _________ Volts = _________ Watts

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 test the system with a return or supply open.

20. OUTPUT

(_______ Strip Watts / ________ Δ T Strip) X _________ Δ T Comp. = _________ Watts

21. APPARENT INPUT

Compressor ________ Amps. X _________ Volts = ________ Watts

22. ACTUAL INPUT

Watts from house or portable watt meter _________ Watts

23. COEFFICIENT OF PERFORMANCE

_________ OUTPUT / _______ ACTUAL INPUT = ____ C.O.P.

Result is plotted on the COP Graph. It should be above the minimum line for a heat pump with the same EER rating or EER 7.8. If it is less and the flow is low, We should rerun both tests with the blower door off.

INSPECTION OF REPAIRS AND ADJUSTMENTS

24. If flow is low, Visually inspect evaporator coil record cleanliness. ________________________.

25. If flow is low, Inspect filter and record condition. ______

26. If flow is low, Visually inspect blower record cleanliness ______________________.

FINAL TESTS - AIR FLOW TEST   PREREAD

NOTE THAT THESE TWO TESTS ARE TIMED - IT IS ESSENTIAL THAT THE READINGS BE TAKEN AT THE TIME SPECIFIED. PERFORM THIS TEST ONLY IF THE AIR FLOW WAS TOO LOW AND YOU ARE DETERMINING WHAT PROPER AIR FLOW WILL DO.

27. Start the heat pump in the emergency heat mode and start your watch to measure times.
28. At EXACTLY 10 minutes record the supply temp ______ then the return temp ____
29. Disable the heat strips.

FINAL EFFICIENCY AND OVERCHARGE TESTS   PREREAD

30. Switch to compressor only heating and restart your stop watch.
31. Install the amp-clamp to measure the compressor current.
32. At EXACTLY 5 minutes record the heat rise ______
33. At EXACTLY 7 minutes measure and record the Amps _______ to the compressor.
34. Record the Watts from the watt meter _____ or Watts from house meter test. _____
35. Record the outdoor air temperature from the outside thermometer _______

FINAL CALCULATIONS

36. AIR FLOW

Strip Heater _______ Amps. X ________ Volts = ________ Watts

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 test the system with a return or supply open.

37. OUTPUT

(_______ Strip Watts / ________ Δ T Strip) X ________ Δ T Comp. = _________ Watts

38. APPARENT INPUT

Compressor _______ Amps. X ________ Volts = _______ Watts

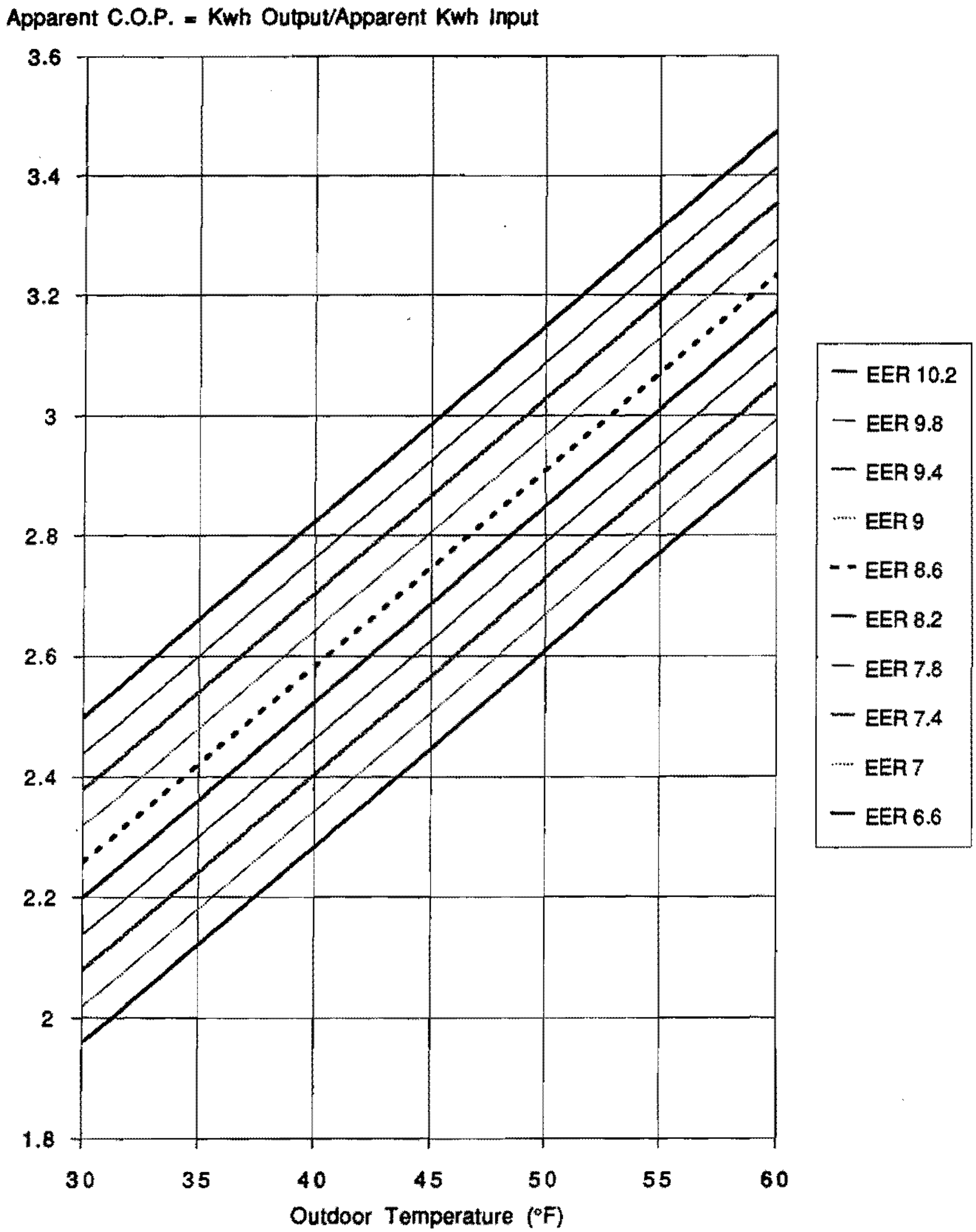
39. ACTUAL INPUT

Watts from house or portable watt meter ________ Watts

40. COEFFICIENT OF PERFORMANCE

________ OUTPUT / _______ ACTUAL INPUT = ____ C.O.P.

Result is plotted on the COP Graph. It should be above the minimum line for a heat pump with the same EER rating or EER 7.8. If it is less and the flow is low, We should rerun both tests with the blower door off.


Apparent C.O.P. = Kwh Output/Apparent Kwh Input
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
30
35
40
45
50
55
60
Outdoor Temperature (°F)
EER 10.2
EER 9.8
EER 9.4
EER 9
EER 8.6
EER 8.2
EER 7.8
EER 7.4
EER 7
EER 6.6

Appendix F

House Data

Appendix F - House Data

Not included in this copy of the report

Appendix G

Materials & Equipment

MATERIALS & EQUIPMENT

TESTED AND RECOMMENDED MATERIALS & EQUIPMENT

(NOTE: Two letter identifiers indicate manufacturers and suppliers found in next section)

DUCT SEALING MATERIALS

Acoustical Sealant	Non-drying, non-hardening TR #936-71A-371
Aluminum Tape	Width = 2", Foil Duct Tape, UL listed #181A JS #G22-703
Cable Ties	Nylon Duct Ties, UL flame class V-2', Length = 32" or longer JS #G31-193
Fiber Mesh	Two inch wide self-adhesive fiberglass fabric PS #0261111, HM
Foam Sealant	Single component expanding urethane foam "Instaseal", PE #550
Mastic	• Non solvent-based duct sealant with fibers. • Must adhere to surface without special cleaning. • Compatible with plastic flex duct "Glencoat", IM
Poly Sheet	Six mil Black Various Sources
Sheet Metal Screws	Self drilling or taper point JS #G31-389, Various Sources
Silicone Caulk	ASTM C920-86 Various Sources

DUCT TEST EQUIPMENT

Deli Wrap	18" wide industrial roll Various Sources
Flow Hood	25-2500 CFM with air density correction SI #CFM-88-3
Small Flow Hood	
Masking Tape	Two-inch Various Sources

DUCT INSTALLATION EQUIPMENT

Tensioning Tool	Nylon Strap and Cable Tie Installation Tool JS #H24-583

BUILDING SHELL SEALING MATERIALS

Acoustical Sealant	Non-drying, non-hardening TR #936-71A-371
Barriers	Coated cardboard designed to keep insulation off under-eave vents. 16" and 24" wide. RS #2036, AD #2036
Chimney Top Damper	"Trap Door" type controlled by chain. Lymance Manufacturing
Drywall	Thickness = 3/8" or 1/2" Various Sources
Foam Sealant	Single component expanding urethane foam "Instaseal", PE #550
Furnace Cement	Non-asbestos, retort cement in cartridge or tub. Various Sources
Galvanized Sheet Metal	Thickness = 24 Guage or thinner. Various Sources
Poly Sheet	Six mil Black Various Sources
Silicone Caulk	ASTM C920-86 Various Sources
V Strip	Plastic or Metal Weatherstrip with <u>permanent</u> attachment. Various Sources

BUILDING SHELL TEST EQUIPMENT

Blower Door	Portable, high flow, precision blower door "Minneapolis Blower Door", EC #1143-1144
Computer , Printer, Program	Sharp Model 1262, EC

BUILDING SHELL INSTALLATION EQUIPMENT

Caulking Gun	Various Sources
Cotton Gloves	Various Sources
Fomo Cleaner	Solvent cleaner for Foam Sealant PE
Tyvek Suits	PE
Neoprene Gloves	Various Sources
Staple Gun	Various Sources
Utility Knife	Various Sources

HEAT PUMP TEST EQUIPMENT

Ammeter/ Voltmeter	0-6, 15, 40 or 60 scale JS #H24-679, JS #H23-196
Carrier Total Test Analyzer	Various Sources
Glycerine Gauges & Manifold	Various Sources
Refrigerant Leak Detector	Various Sources
Stop watch	Provides precision timing for all heat pump tests Various Sources
2 pt. Digital Thermometer	Measures supply & return temperatures & outdoor temperature JS #H24-750

HEAT PUMP INSTALLATION EQUIPMENT

Charging Cylinder	Used to accurately remove & add refrigerant to heat pump, 5 lb. capacity. JS #H85-181, Robinair # 43678-A
Refillable Container	Holds recovered CFC's Various Sources
Refrigerant Reclaim System	Used to avoid discharge of refrigerant and to recover it for use. *Use one per contractor located at shop.* VS #LV 30-4
Vacuum Gauge	Measures to 50 microns Robinair #14010 or equivalent
Vacuum Pump	Evacuates to 50 microns Robinair #15001 or equivalent
Valve Core Replacement Tool	Allows replacement of valve cores without evacuating system JS #H24-611

DOMESTIC HOT WATER MATERIALS

Low Flow Shower Heads	G.P.M. Various Sources
Vinyl Tape	Various Sources
Water Heater Jackets	1 1/2" to 3" thick Various sources
Water Heater Straps	Various sources

DOMESTIC HOT WATER TEST EQUIPMENT

Stopwatch	Various sources
Two Quart Pitcher	Various sources

TESTED AND NOT RECOMMENDED MATERIALS & EQUIPMENT

DUCT SEALING MATERIALS

Cloth Duct Tape	JS #G21-155
Mastic	• Duct sealant "Galvagrip", GS, "Air-Lock" JS #G89-799

HEAT PUMP CONTROLS

Outdoor Cut Out	Open on rise adjustable outdoor air thermostat. JS #L37-367, JS #136-107, JS #B10-843, JS #L36-931 "Farm-o-Stat" HW #T631A1030, White Rogers #2B61-186, White Rogers #265-1
Thermostat- Digital Heat Pump	With two stage heating and ramp up recovery feature White Rogers #1F92-6, JS #137-481

MATERIALS & EQUIPMENT TO TEST NEXT PROGRAM

DUCT SEALING MATERIALS

Acoustical Sealant	Non-drying, non-hardening OS #RS225
Mastic	• Non solvent-based duct sealant with fibers. • Must adhere to surface without special cleaning. • Compatible with plastic flex duct RC #6, FO #38-00

BUILDING SHELL SEALING MATERIALS

Backdraft Damper	In-duct retrofit damper gravity close.

HEAT PUMP CONTROLS

Outdoor Cut Out	Open on rise fixed outdoor air thermostat. "Accustat", PS #OT11 40°F

Suppliers & Manufacturers

ADO Products (AD)
7887 Fuller Road
Eden Prairie, MN 55344

Control Tech (CT)
1300 Industrial Road #4
P.O. Box 1524
San Carlos, CA 94070
Tel: (415)593-2111
Fax: (415)593-9629

D.M. Figley (DM)
10 Kelly Court
Menlo Park, CA 94025
Tel: (415)329-8700

Energy Conservancy (EC)
920 West 53rd Street
Minneapolis, MN 55419
Tel: (612)827-1117

Foster Products Corporation (FO)
3200 LaBore Road
Vadnais Heights, MN 55110

Gow Supply (GS)
1492 Egbert Ave.
San Francisco, CA 94124
Tel: (415)822-6150

Hamilton Materials (HM)
345 W. Meats Ave.
Orange, CA
Tel: (714)637-2770

I.M. Distributors (IM)
5061 24th Street
Sacramento, CA 95822
(916)736-9060

92.015

Johnstone Supply (JS)
2329 Lexington Street
Sacramento, CA 95815
Tel: (916)922-6503

MANCO (MA)
3350 Scott Boulevard
Building 55
Santa Clara, CA 95054
Tel: (408)496-6611
Fax: (408)496-6148

Ohio Sealants, Inc. (OS)
7405 Production Drive
Mentor, OH 44060
Tel: (800)321-3578

OMEGA Engineering (OE)
One Omega Drive
Box 4047
Stamford, CT 06907-0047
Tel: (203)359-1660
Fax: (203)359-7900

Pacific Supply (PS)
355 Bayshore
San Francisco, CA 94124
Tel: (415)285-1010

Positive Energy Conservation Products (PE)
325 Canyon Blvd.
Boulder, CO 80302

PSG Industries, Inc. (PS)
1225 Tunnel Rd.
P.O. Box 157
Perkasie, PA 18944-01575

RCD Corporation (RC)
2310 Coolidge Avenue
Orlando, FL 32804

RSA (RS)
11492 Refinement Road
Rancho Cordova, CA 95742
Tel: (800)221-3359

Shortridge Instruments, Inc. (SI)
7855 E. Redfield Road
Scottsdale, AZ 85260-3430
Tel: (602)991-6744

Tremco (TR)
3735 Green Road
Beachwood, OH 44122
Tel: (800)321-3578

Van Steenburg (VS)
Engineering Laboratories, Inc.
1900 S. Quince Street
Denver, CO 80231
Tel: (303)696-0113
Fax: (303)696-1077

Appendix H

Savings Calculation Methodology

Appendix H

SAVINGS METHODOLOGY

The savings analysis in this report uses multiple savings estimate methodologies in order to obtain for each item the most empirically based savings estimates possible. Empirically based estimates usually result in lower but more accurate savings estimates than simple engineering calculations.

The steps of the analysis are:

1) Estimate savings for each retrofit measure individually.
2) Combine the savings for each unit in a manner that takes interactions into account.
3) Combine the individual savings into an overall savings for the group.
4) Utilize the group savings estimates along with cost and lifetime data to calculate benefits to the participant and utility, benefit cost ratios, and net lifetime benefit.

SAVING FOR INDIVIDUAL MEASURES

Disconnected Ductwork

Large savings have been achieved on a limited test of BRMC's Forced Air Systems Technology (FAST) program (Proctor, 1984 and Proctor, 1986). In a test of the FAST technology using the Solar Energy Research Institute's Short Term Energy Monitoring (STEM), an average 50 percent of the heat leaving the forced air appliances was lost to crawl spaces or unheated basements. On two houses in these STEM tests, work was concentrated on the duct system to eliminate leaks (no duct insulation was added). The measured heating energy savings from reducing duct leakage alone was 30.6% on one house and 46.4% on the other.

A larger test was run by Cummings (1990). The air conditioners of thirteen houses were instrumented with kWh meters. The thermostat set points were maintained constant and the meters were read daily and regressed against outdoor temperature. The houses were tested before and after the ducts were sealed. The resultant savings averaged 18.8% of the cooling use. Some of these units had catastrophic duct leakage. Based on that test we have conservatively estimated the savings from catastrophic duct leakage at 15%.

Diffuse Duct Leaks

Estimation of the kWh lost due to diffuse duct leakage is contained in Appendix I. That analysis is dependent upon determining the kWh lost due to infiltration. It would be possible to estimate this load at 40% of the total heating load. However, it is more desirable to have an infiltration load determined by the air tightness of the individual house. This is accomplished by a multiple regression utilizing Data Desk Professional software from Odessa Corporation.

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

The results of a multiple regression of Initial heating kWh/sq.ft. against Initial ACH50, fires/week, etc. includes the regression coefficient for Initial ACH50. Coefficient .12723 Standard error .0584.

As a check: the mean I.ACH50 (11.328) X .12723 = 1.441 kwh/sf.

1.441 / 3.54 (mean Initial heating kWh/sq.ft.) = 40.7%

Thermostat Cut Out

Estimation of the savings due to to the strip heat cut out is described under "Estimate of Energy Savings Due to Outdoor Cut Out Control" in the main report. The model was checked against actual use on the monitored sites and was found to be in good agreement. While a savings of 16% is quite possible for a cut out set at 40°F, the savings is highly dependent on the actual setting. For this reason the savings was estimated at 8% for the work done during the pilot. With a more accurate cutout the savings is estimated at 10% for the production program.

Correct Air Flow and Correct Charge

The savings for air flow through the inside coil and the savings from correcting the charge begin with the same analysis.

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

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

The predictor variables used in the regression are change in air flow as a percent of specified air flow and incorrect charge as a 0/1 variable. The analysis removes two outliers from the regression which otherwise drive up the savings. The results are:

air flow %	coefficient	.5853	standard error	.1376
charge	coefficient	.2046	standard error	.0414

The resultant savings estimate is 20.5 % for correcting charge. This is reduced by 10% to provide a conservative savings estimate of 18.4%

Fan Off Time Delay

Monitored sites were run for individual cycles to study the effect of leaving the fan on at the end of the cycle. The results are described in the section of the main paper entitled "Short Term Monitoring Results."

House Medic

The savings for House Medic are from a "PRISM-like" analysis of utility use on 28 single family homes. The analysis is contained in Proctor (1988). The savings from that study for the program properly applied was 9.5%. When that work was done there was less emphasis in the program on sealing ductwork, but some duct sealing was done. Since no study directly applies, the savings are estimated as 15% with ductwork and 7.5% without.

Total Program Savings

The calculation of estimated savings for the total program is accomplished using the following method:

- The savings for each individual house in the sample is calculated "in series." This means that the savings are not additive, but discounted by the savings that has occurred due to other program items that were applicable to that house. This takes the form: $(1\text{-sav}\%_1) \times \text{sav}\%_2$ etc.
- The savings for all fifty houses in the sample is then averaged. This produces an unweighted average savings for the program.

Net Lifetime Benefit Analysis

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 (7250 kWh heating and 661 kWh cooling. This benefit is therefore primarily for heating. The calculation used lifetimes of 5 years for heat pump measures (based on the average remaining life of the heat pumps in the study) and 15 years for ductwork and weatherization measures.

In some cases the Program Benefits were adjusted to correct for a revised savings estimate. When this occured the Net Benefits and Benefit/Cost Ratios were recalculated.

Appendix I

Air Changes and Duct Leakage

PERCENT OF TOTAL INFILTRATION DUE TO DIFFUSE DUCT LEAKS

Fan Off 7.74%

Fan On 37.48%

Heating Season Average 16.52%

HEATING USE DUE TO DIFFUSE DUCT LEAKAGE

912 KWH

13% OF ANNUAL HEATING USE

Appendix I 10/16/90

H.P. Number Heat Pump ID	Heat Pump CFM Delivery	House Size sq.ft.	Pump Size	Diffuse D.Leakage at 50 pa.	House Leakage at 50 pa.	ACH Nat. LBL	ACH at 50 pa.
AVERAGE	***1235***	***2244***	***39833***	***249***	***3711***	***0.67***	***11.43***
1	564	2175	24000	58	3291	0.71	11.34
2	1286	2015	33400		3062	0.57	11.39
3	864	4062	23400				
4	1725	3417	36000	124	7449	0.80	13.96
5	1727	1986	48000	880	6334	1.19	23.75
6	1151	2095	37000	52	2535	0.45	9.07
7	1435	1643	42000	422	3274	0.75	14.94
8	897	1626	32000	240	2349	0.54	10.77
9	1020	2304	49000	404	4300	0.88	14.00
10	1327	2050	46000	108	3930	0.65	12.32
11	1044	2300	38500	127	5651	0.90	14.43
12	1879	1792	40000	210	2697	0.54	10.88
13	1398	2563	36000	294	7022	1.03	16.44
14	914	3200	39000		7416	1.24	17.38
15	1036	2688	48000	225	2492	0.29	4.63
16		1176	32000	367	2655	0.85	16.93
17	948	1680	29400	202	3168	0.88	12.57
18	950	1300	34200	114	1627	0.45	9.05
19	1138	1875	38000	131	6803	1.70	27.21
20		Same House	24000	164			
21	961	2244	40500	230	3097	0.62	9.97
22	1373	2500	51000	302	4245	0.73	10.18
23	1163	1904	28600	188	1430	0.28	5.63
24	652	1760	28000	104	1228	0.26	5.23
25	1087	4032	33600	89	3293	0.38	6.12
26	751		24800	140			
27	1441	3700	46500	173	4663	0.77	8.59
28	2133	2374	48500	167	2943	0.58	9.29
29	1249	1392	35500	284	2593	0.64	12.70
30		2300	42000	370	3588	0.73	11.70
31	1387	1482	41000	255	3340	0.74	16.29
32	1620	2126	45000	197	2272	0.32	7.72
33	1766	3505	43000	109	7593	1.09	16.24
34	1034	1902	42000	123	2677	0.35	7.03
35	1227	2047	42000	198	1783	0.28	5.50
36	1352	1728	33800	136	1974	0.34	6.85
37	1379	2178	47000	285	4668	1.17	13.08
38	1567	2208	38500	286	2384	0.40	8.09
39	1112	1484	38000	315	2834	0.30	5.53
40	1071	1614	34500	217	3109	0.64	12.84
41	1260	1698	51000	336	4462	0.72	14.33
42	1553	2680	58000	667	6451	1.13	18.05
43	1626	2746	47000	250	2129	0.29	5.81
44	763	2008	38000	229	1332	0.25	4.97
45	1124	2382	46000	291	2661	0.38	6.65
46	1273	1704	38000	122	2849	0.60	12.08
47	1149	3300	47000				
48	1197	1779	36000	211	3643	0.70	12.79
49	1103	2200	60000	493	3872	0.66	10.56
50	1138	Same House	37800	490	6478	0.86	12.20
51	1442	2781	59000	348	4751	0.92	10.25

Infiltration and Heat Loss due to Duct Leakage Calculation Methods

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

Qadd = Infiltration added by duct leakage
Qnat = Natural infiltration
Qfan = Air handler fan flow
Fr = Return leak cfm ÷ Qfan
Fs = Supply leak cfm ÷ Qfan
Fa = Qadd ÷ Qfan

Assumptions include:
Neutral level at .5 height

With the blower on the additional infiltration due to the duct leaks (Qadd) is:

When (Fmax-Fmin) X Qfan ≤ 2 Qnat
Qadd = [.5 X (Fmax - Fmin) + (1-Fmax) X Fmin] X Qfan

When (Fmax-Fmin) X Qfan ≥ 2 Qnat
Qadd = [Fmax - Fmin + (1-Fmax) X Fmin - (Qnat/Qfan)] X Qfan

Assumptions used in this calculation for the heat pump homes include:

Supply and return leak fractions are random and normally distributed.
Supply and return leak fractions for these houses are similar to those tested by Robison (1988)

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

Assumptions include:
The blower runs 30% of the time when heat is needed.

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 =
.3 X Qadd ÷ Qnat + .7 X duct CFM50 ÷ house CFM50

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

ΔTf = Temperature rise through heat pump
ΔTh = Inside to outside temperature differential
Ef = Actual output of furnace (btuh)
Ea = Heat loss due to duct leakage (btuh)
Dl = Distribution loss due to leaks (%) = Ea ÷ Ef

Assumptions include:
Air handler return leaks are at outdoor temperature

The distribution loss due to duct leaks Dl = Fa X (ΔTh ÷ ΔTf) + Fs

Appendix J

Implementation Plan

I. Introduction

A. BACKGROUND

The implementation and training plan is a portion of the PG&E Heat Pump Efficiency and Super Weatherization Pilot Project. A complete report of the field results of this project is contained in the Field/Technical Report submitted on June 1, 1990.

The Heat Pump Efficiency Pilot Project was initiated to address the problem of a high level of complaints from homeowners with heat pumps in PG&E's Drum Division (near Auburn, California). There were two major components of the project:

1) identify the major problems with existing residential heat pump installations;
2) design a system to correct those problems.

The system to correct the problems is described in this Implementation Plan.

B. RESULTS OF THE PILOT PROJECT

The pilot project found that resolvable mechanical equipment problems were the source of high bills and high bill complaints in the houses studied and that the existing heating contractor infrastructure had failed to diagnose or solve these problems.

Problems with Existing Infrastructure

In spite of the fact that most of the sites had recent maintenance by professional personnel, 84% of them had at least one major problem with their heat pump system.

Problems associated with the existing heating contractor infrastructure include:

1) Failure to diagnose the true cause of the problem, sometimes resorting to "Heat pumps just work that way."
2) Selling the homeowner unnecessary new equipment.
3) Failure to repair all significant problems while on site. This includes, leaving the inside coil clogged, adding refrigerant without repairing the leak, leaving the unit with too much or too little charge, leaving major duct leaks and numerous others.

Heat Pump, Control, Ductwork and Building Shell Problems

Problems identified on the project houses in order of their occurrence were:

1) Disconnected or leaky ductwork.
2) Thermostat management resulting in unnecessary use of the electric resistance strip heat.
3) Inadequate air flow through the inside coil.
4) Incorrect charge and refrigerant leaks.
5) An excessively leaky building shell.

II Program Design

A. GOALS

The Implementation Plan is designed to produce verifiable space heating savings of 27% or more in order to achieve the following PG&E goals:

1) reduce homeowner complaints;
2) improve customer perception of heat pumps;
3) facilitate customer acceptance of high efficiency heat pump programs for retrofit and new construction;
4) provide net utility lifecycle benefits in line with the collaborative process.

In order to justify PG&E's financial participation the program is designed to accomplish:

1) actual installation of the highest volume cost effective items;
2) accurate diagnosis of additional problems;
3) adequate incentive for the home owner to pay for the remaining cost effective items from the diagnosis;
4) increased customer perception of PG&E as an ally in controlling heating costs.

These goals can only be accomplished when the technicians who deliver the service are given a comprehensive procedure, adequate training to follow that procedure, time to complete the procedure, and are held accountable to the procedure.

B. SYSTEM SUMMARY

The plan takes a pro-active approach, actively seeking out customers likely to have problems without regard to whether they have complained. Marketing is targeted to heat pump customers whose electric use profiles indicate that they would benefit from the service.

The delivery system adds the controls necessary to overcome the problems in the existing delivery infrastructure. This system could effectively insure the proper diagnosis and repairs for a wide range of problems from the heat pump to the building shell and duct work. The following delivery system of initial testing, modifications, repairs and retrofits, and final testing is recommended:

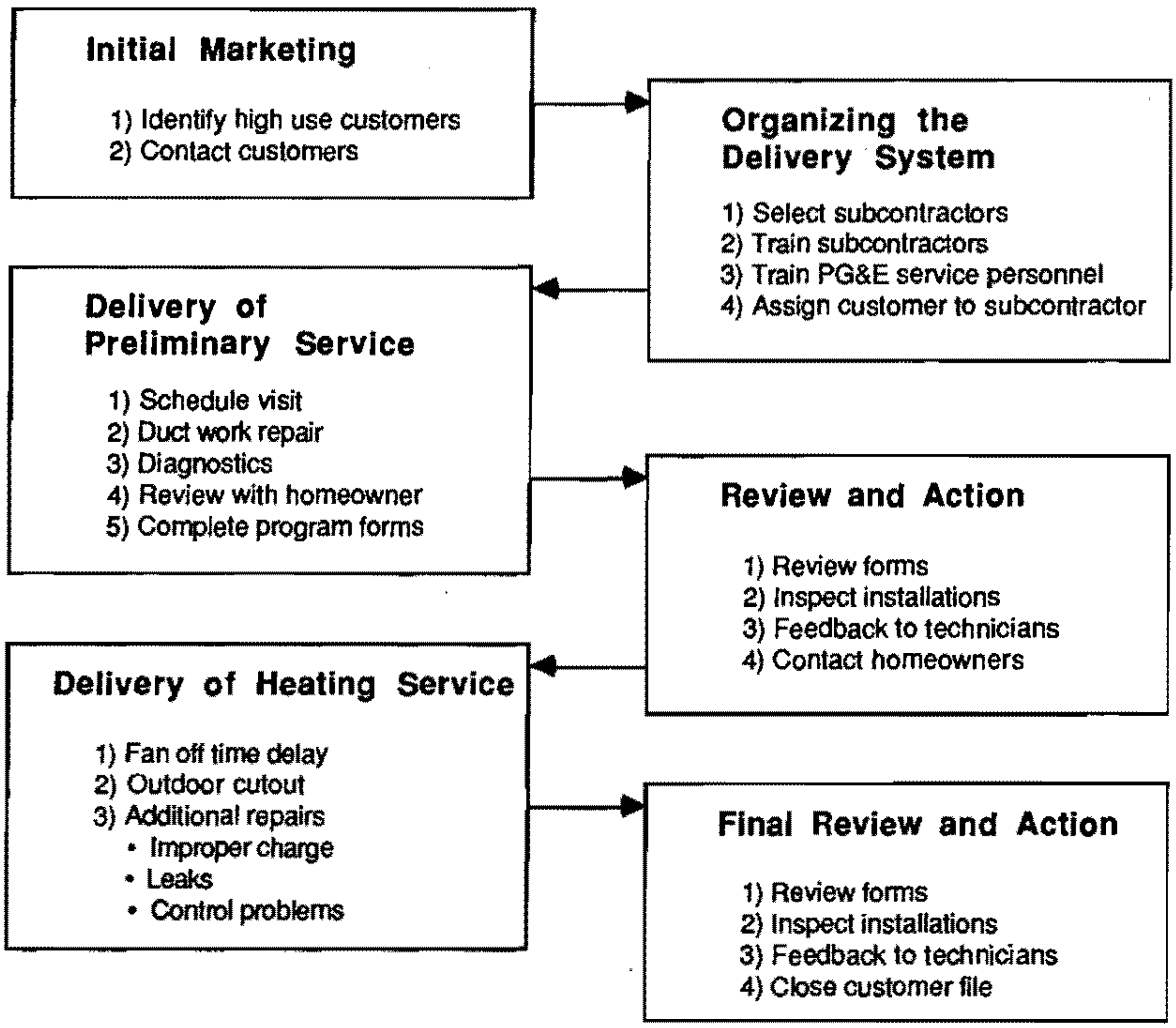
1) Data is recorded for every step of the process so that:
    - the condition of the heat pump, the distribution, and the structure can be accurately analyzed;
    - the performance of the technician can be determined.
2) Detailed data is reviewed by the program manager to determine:
    - what feedback the technicians should receive;
    - whether or not the modifications are successfully completed and if a follow-up trip is warranted to obtain successful completion;
    - if the processes involved are accomplishing the desired results or needed to be streamlined or changed.
3) The program manager gives the feedback, orders the follow-up visit or makes the revisions as necessary.
4) A sample of the sites are inspected to determine if the final condition of the units is being accurately reported and if the modifications are in place and operating properly.

C. PROGRAM STRUCTURE AND RESPONSIBILITIES

In this plan there are four entities:

1) PG&E - responsible for the initial marketing effort.
2) The contracted program administrator - responsible for program flow, quality control and training.
3) The weatherization subcontractor - responsible for ductwork repair and initial diagnosis.
4) The heating subcontractor - responsible for work on the heat pump and controls.

Figure 1. Program Structure



Initial Marketing

PG&E would identify all their customers in heat pump areas that fit both of the following criteria:

1) have an annual electricity use exceeding 14,600 kWh;
2) have an average winter heating use (exceeding their base use) of 30 kWh/day. (Average winter heating use is calculated by subtracting the average daily use in September from the average daily use in December, January and February.)

This pool of potential participants is the target of PG&E's marketing effort for this program. The goal of this marketing is to produce a participant pool of 500 homes that are supplied to the program manager at a rate of 25 per week

PG&E remains close to its customer by playing this highly visible initial marketing role.

Organizing the Delivery System

Program management would be provided through a company under contract to PG&E. The initial task would be to write bid specifications for the subcontracting process. These specifications would include tight specifications on the technical and logistical performance of the subcontractors. The potential subcontractors are then contacted and multiple heating and weatherization contractors are chosen.

The program manager's second task would be to provide training to PG&E customer service personnel. This will assist PG&E in dealing with complaints by heat pump customers and will make the marketing of this program easier.

The heat pump and weatherization technicians working for the subcontractors must be specially trained and certified to perform work under the program. This training is the responsibility of the program manager.

Success depends on creation and delivery of a technical service beyond that currently available. Selecting and training subcontractors is critical to achieving success. In order to maintain quality the program administration will remain independent of the subcontractors.

Utilizing multiple subcontractors insures that deviations from the program can be corrected.

Delivery of Preliminary Service

The preliminary service would be provided by the weatherization subcontractor. Utilizing a list of participants supplied by the project manager the weatherization subcontractor would schedule the initial site visit.

Two technicians from the weatherization subcontractor will spend an average of four hours at each residence. They will arrive at the site with all the necessary materials to do substantial duct repair. One technician will immediately begin on duct repair. Using the forms and procedures developed in the pilot project the technician will:

1) repair all disconnected ducts;
2) eliminate repairable restrictions in the duct work;
3) reduce the diffuse duct leakage below 150 CFM at 50 pa. house pressurization.

The lead technician will begin measurement of the duct leakage and diagnosis of the heat pump. Using the forms and procedures developed in the pilot project the technician will accomplish tasks in this order:

1) measure initial heat pump air flow and inform the duct technician of suspected restrictions;
2) diagnose control problems;
3) measure interim duct leakage and inform the duct technician of the existing leakage;
4) measure the house leakage at 50 pa.
5) assist in sealing the duct leakage beginning with leaks concealed behind the return air and delivery registers;
6) when duct leakage has been reduced below 150 CFM, test the final air flow and COP of the heat pump.

Armed with diagnostic information, and having already provided a valuable service, the lead technician reviews the condition of the system with the homeowner, reviews work that has been completed, discusses additional work needed, and presents the incentives available. This individual will secure customer participation in follow-up services.

The results from the initial site visit are conveyed to the program manager for review and action.

This initial visit alone will solve almost half of the low airflow problems, repair 100% of the disconnected ducts, and significantly reduce the diffuse duct leakage problems. In addition the heat pump efficiency and house infiltration will be tested thereby identifying any additional areas that need program attention.

To successfully market this program, entry barriers for customers must be very low. Half the customers contacted for the pilot program refused to participate despite the fact that services provided bore no financial cost. In order to insure that these essential items are accomplished on the units that need the service the initial visit should be free.

Review and Action

The program manager reviews the work done by the weatherization contractor and takes action in a number of ways:

1) provides feedback to the technicians on every job within 7 days;
2) inspects a sample of the jobs to insure the reported work has been accomplished;
3) regulates the contractors through feedback, call backs, and sanctions if necessary;
4) provides a list of heating service participants to the heating subcontractor.

Delivery of Heating Service

The heating service would be provided by the heating subcontractor. Utilizing the participant list supplied by the project manager the subcontractor would schedule the site visit.

A technician from the heating subcontractor will provide services on a fixed cost basis and only as specified by the project manager after form review. Using the forms and procedures developed in the pilot project they will:

1) add a fan time delay to all units;
2) install an accurate outdoor cut out on all units not having one;
3) repair control problems diagnosed in the initial visit;
4) repair improper charge and leaks diagnosed in the initial visit;
5) clean indoor coil if diagnosed in the initial visit.

The results from the heating service visit are conveyed to the program manager for review and action.

The heating service work would be subsidized with PG&E incentives that reflect the value of the individual items to the company.

Final Review and Action

The program manager reviews the work done by the heating contractor and takes action in a number of ways:

1) provides feedback to the technicians on every job within 7 days;
2) inspects a sample of the jobs to insure the reported work has been accomplished;
3) regulates the contractors through feedback, call backs, and sanctions if necessary;
4) closes the file with a letter to the customer.

III Program Economics

The economic goal of the program is to achieve maximum cost-effective energy savings for each site by combining PG&E subsidies with customer contributions. The ideal customer contribution would achieve highest energy savings at the lowest possible utility cost.

The services must be of high quality and controlled cost. The program uses the least costly method of delivering the services. During the initial visit well-trained, but moderately paid technicians are utilized to obtain the initial data and repair the most common problems. The higher cost skilled heat pump service personnel are utilized on a fixed cost basis and only to accomplish the standard elements and repairs identified at the first visit.

A. SAVINGS, COSTS AND BENEFITS

Table A shows the projected energy savings, costs and net lifecycle benefits for the program.

Table A. Projected Program Savings and Total Cost (including interactive savings effects and administrative costs)

Average Heating Energy Savings	27%*
Average Cooling Energy Savings	22%*
Utility Cost	$600
Utility Net Lifecycle Benefit	$259
Participant Cost	$50 to $350
Participant Net Lifecycle Benefit	$2,597

*Based on full participation in the program.

These savings are dependent on three items:

1) The actual heating and cooling use of the participants;
2) The actual mix of problems that occur on participants' heat pumps;
3) Whether or not the problems are properly diagnosed and reliably repaired.

The program design addresses these three items by targeting the program delivery to high users, by continuous evaluation of the actual problems found in the field, and by utilizing a tight system of checks, feedback and control.

Table B indicates the heating energy savings for individual retrofit measures, taken separately (excluding any interactive effects). Also shown are estimated labor and materials costs and the calculated net lifecycle benefit.

Table B. Heating Energy Savings and Cost Estimates for Individual Retrofit Measures

Retrofit Measure	Average Heating Energy Savings	Est. Cost per Site	Percent Utility Contribution	Net Owner Lifecycle Benefit	Net Utility Lifecycle Benefit
Duct and House Diagnostics		$60	100%		
Heat Pump Diagnostics		$30	100%		
Repair Disconnected Ducts	15.0%	$35	100%	$1,638	$562
Repair Diffuse Duct Leaks	7.5%	$150	100%	$952	$147
Install Thermostat Cutout	10.0%	$100	25%	$462	$82
Correct Low Air Flow	5.6%	$50	50%	$312	$52
Install Fan Off Time Delay	3.6%	$50	50%	$167	$23
Repair Leaks and Correct Refrigerant Charge (approx. 30% of units)	18.4%	$200	25%	$777	$215
House Medic (alone)	15%	$530	25%	$1,281	$470
House Medic (after duct repairs are already done)	7.5%	$430	25%	$612	$194

B. IMPLEMENTATION PLAN BUDGET

This budget and schedule assumes that PG&E implements a plan to accomplish heat pump system improvements on 400 to 500 units.

These improvements are accomplished by 4 weatherization crews who undertake initial ductwork and diagnostic work, and 3-4 heating contractor technicians who conduct follow up work, including installation of time delays and accurate outdoor cutouts an all participant's units, and air flow and refrigerant charging work for participants that need those items.

The plan has a two month start up period during which administrators locate, train, certify, and retain subcontractors who are willing to conform with program quality and price specifications.

Three months into the pilot, it is assumed that additional training will be required because some subcontractors will have been lost or terminated, and personnel changes within subcontractor organizations will have led to attrition of workers capable of doing the work consistent with program guidelines.

Initial Heat Pump Work

Initial heat pump work includes duct diagnosis and sealing, heat pump and shell diagnosis.

480 Units @ $275.00/unit	$132,000.00
Closing Commission (317 units @ $10.00/unit)	$3,170.00
Subtotal Initial Work	**$135,170.00**

Secondary Heat Pump Work

This assumes that 66%(317) of the customers decide to purchase subsidized second level work consisting of outdoor cutouts and time delays, 24%(115) receive air flow work, and 20%(96) will have their charge corrected.

Cutouts and Time Delays (317 sites @ $150.00/site)	$47,550.00
Air Flow Work (115 sites @ $50.00/site)	$5,750.00
Charging Repairs (96 sites @$200.00/site)	$19,200.00
Customer Contribution-Cutouts and Time Delays (317 sites @ $100.00/site)	($31,700.00)
Customer Contribution-Air Flow Work (115 sites @ $25.00/site)	($2,875.00)
Customer Contribution-Charge Correction (96 sites @ $150.00/site)	($14,400.00)
Subtotal Secondary Work	**$23,525.00**

Program Administration

Training and certification includes four-three day sessions (two each for crews doing initial work and secondary work). Sessions will be held during the start-up phase and after the program has been operating for three months.

Two 3 Day Trainings-Ductwork & Diagnostics Crew	$6,000.00
Two 3 Day Trainings-Heat Pump Technicians	$6,000.00
Miscellaneous Training-Related Expenses	$1,000.00
Subtotal Training and Certification	**$13,000.00**

Start-Up (Includes preparing bid specifications, reviewing bids and contractor qualifications, coordinating with PG&E)	$15,750.00
Quality Control Activities (Paperwork Review, Inspections, Contractor Supervision @ $200.00/unit)	$96,000.00
Tools	$5,500.00
Total Operational Administration	**$117,500.00**

Subtotal Initial and Secondary Work	$158,695.00
Subtotal Training, Certification, & Administration	$130,500.00
TOTAL BUDGET	$289,195.00

Appendix K

Training Plan

I. Introduction

A. BACKGROUND

The implementation and training plan is a portion of the PG&E Heat Pump Efficiency and Super Weatherization Pilot Project. A complete report of the field results of this project is contained in the Field/Technical Report submitted on June 1, 1990.

The Heat Pump Efficiency Pilot Project was initiated to address the problem of a high level of complaints from homeowners with heat pumps in PG&E's Drum Division (near Auburn, California).

The system to correct the problems is contained in the Implementation Plan submitted on June 25, 1990.

This Training Plan describes a method of training the technicians for and during their participation in the program.

B. PRINCIPALS

The training plan is based on basic three principals:

1) It cannot be assumed that technicians, supervisors, inspectors and contractors know how to do what is required by the program.

   In spite of the fact that most of the sites in the pilot project had recent maintenance by professional personnel, 84% of them had at least one major problem with their heat pump system.

2) Classroom or laboratory training cannot compare with work in the field combined with rapid and adequate feedback.

   This integrates the program design with the initial training. The form review, inspection and feedback are essential to obtaining and maintaining technician competence.

3) The technician must be working at a rate sufficient to learn from each unit.

   The technicians must be doing at least three units per week following the initial training. A higher number of units will substantially improve the technician learning curve.

II Discussion

The training plan describes a method of training the duct and diagnostic technicians responsible for the first house visit. It also lists the training for the heating technician that accomplishes the follow-up visit.

A. LOGISTICS

Training Personnel

The instruction should be provided by individuals who have:

1) direct field experience with the tasks described;
2) thorough familiarity with the forms and procedures including actual field use;
3) experience in delivering a high production, high quality controlled program.

One trainer should be provided for every four technicians during the second and third day of the initial training.

Schedule

Both sets of technicians follow similar training patterns. Three days of initial training followed by review and feedback on every house. The review, inspection and feedback is detailed in the Implementation Plan.

The first day consists of classroom instruction and interaction listed in the tables that follow. This instruction would include familiarization with the equipment and materials used in the program. Testing to insure comprehension is essential in the first day.

The second day is spent in one house with the trainer. The technicians follow the forms provided, in a step by step manner with close guidance being provided by the instructor.

The third day is spent with two technicians at a house for one-half day. The technicians follow the form with the trainer present as observer. After the technicians are finished they all return to the classroom to cover the following points:

1) problems encountered and solved on day two and three,
2) the condition and results on all the units completed so far,
3) known "unusual" cases and how to approach them,
4) review of the program goals, policies and results.

B. CONTENT

The training content for the first day is contained in the Duct and Diagnostic Technician Training Table and the Heating Technician Training Table. Both contain similar material, however the emphasis for each concentrates on the technician's specific areas of responsibility.

Duct and Diagnostic Technicians

Two technician crews from each weatherization subcontractor will be trained. They will be trained, utilizing the forms and procedures developed in the pilot project, to:

1) repair all disconnected ducts;
2) eliminate repairable restrictions in the duct work;
3) reduce the diffuse duct leakage below 150 CFM at 50 pa. house pressurization.

The lead technician will also be trained to:

1) measure initial heat pump air flow and spot restrictions;
2) diagnose control problems;
3) measure duct leakage;
4) measure the house leakage;
5) test the COP of the heat pump;
6) review the condition of the system with the homeowner;
7) recommend additional work needed and review the incentives available;
8) secure customer participation in follow-up services.

DUCT AND DIAGNOSTIC TECHNICIAN TRAINING PLAN			
	Subject	**Material**	**Objectives** (Participants will be able to:)
Module #1	Basic Heat Pump	The heat pump, components, controls and operation	• explain the basic operation of a heat pump • explain the difference between heat from the strip heaters and from the compressor unit. • explain the operation of two stage heat pump controls • explain the meaning of COP, EER & SEER
Module #2	The Program	Table.B, work flow, reporting, feedback, pay and desired results	• identify program components • explain the reason for the order of the program components
Module #3	Basic Problems	Table.G, the pilot project,	• identify the three basic problem areas of heat pump inefficiency • identify the two most frequent problems in each area
Module #4	Air Flow Problems	Fig 2 & 3, App. C, Table C, comfort, flow restrictions & blower speed	• describe the problems associated with inadequate air flow • report the magnitude of the efficiency drop due to reduced air flow • describe the effect of high air flow • rank the most likely causes of air flow problems • calculate air flow using the temperature differential method

	Subject	Material	Objectives (Participants will be able to:)
Module #5	Charge Problems	COP vs Charge, App. C, Table C, air conditioning efficiency, previous service calls	• describe the problems associated with both under and over charge • recognize the warning signs, including customer comments, that indicate charge might be incorrect • demonstrate knowledge that charge cannot be checked unless air flow is correct • demonstrate use of the COP test form to determine if charge is likely to be incorrect
Module #6	Refrigerant leaks	Trane & York Manuals, App. C, Table C	• list the potential causes of refrigerant leaks • explain the proper method of repairing refrigerant leaks
Module #7	Other Potential Problems	Trane and York Manuals, App. C, Table C	• list at least three other potential problems
Module #8	Control Problems	Figure 9 &10, Table K & App. C, 1st. stage strip heat, manual set back & "dueling"	• identify the three main control problems on heat pumps • describe how to solve the three major problems • role play "selling the cut out" to the customer

	Subject	Material	Objectives (Participants will be able to:)
Module #12	Testing Air Flow	App. C, ammeter, voltmeter, digital thermometer, repair of restricted air flow, avoiding technician caused refrigerant and duct leaks	• illustrate where the thermocouple probes must be placed • demonstrate knowledge of the effect on air flow calculation and COP if probes are incorrectly placed • fill out the air flow test form completely • identify how to repair a collapsed flex duct • identify how to clean the indoor coil • identify the potential hazards of cleaning the indoor coil and how to avoid them
Module #13	Customer Interaction	Review, role playing interactions with the customer	• demonstrate understanding of the importance of engaging the customer as an ally • explain the need for changing the filter • explain the need for a technician to come and fix the charge. • explain the need to keep registers open.

Heating Technicians

At least two technicians from each heating subcontractor will participate. They will be trained, utilizing the forms and procedures developed in the pilot project, to:

1) add a fan time delay;
2) install an outdoor cut out;
3) repair control problems;
4) repair improper charge and leaks;
5) clean the indoor coil.

HEATING TECHNICIAN TRAINING PLAN			
	Subject	**Material**	**Objectives** (Participants will be able to:)
Module #1	Basic Heat Pump	The heat pump, components, controls and operation	• explain the operation of two stage heat pump controls • explain the meaning of COP, EER & SEER
Module #2	The Program	Table.B, work flow, reporting, feedback, and desired results	• identify program components • explain the reason for the order of the program components
Module #3	Basic Problems	Table.G, the pilot project,	• identify the three basic problem areas of heat pump inefficiency • identify the two most frequent problems in each area
Module #4	Air Flow Problems	Fig 2 & 3, App. C, Table C, comfort, flow restrictions & blower speed	• describe the problems associated with inadequate air flow • report the magnitude of the efficiency drop due to reduced air flow • describe the effect of high air flow • rank the most likely causes of air flow problems • calculate air flow using the temperature differential method

	Subject	Material	Objectives (Participants will be able to:)
Module #5	Charge Problems	COP vs Charge, App. C, Table C, testing for charge in the heating mode, migrating refrigerant, refrigerant recovery, Carrier "Total Test"	• describe the problems associated with both under and over charge • demonstrate an understanding of the manufacturers methods of checking charge • demonstrate knowledge that charge cannot be checked unless air flow is correct • demonstrate use of the COP test form to "chase COP" • demonstrate knowledge of the effect of moisture in the system and how to test for it
Module #6	Refrigerant leaks	Trane & York Manuals, App. C, Table C	• list the potential causes of refrigerant leaks • explain the proper method of repairing refrigerant leaks including the use of nitrogen and evacuation
Module #7	Other Potential Problems	Trane and York Manuals, App. C, Table C	• list at least five other potential problems, how to diagnose and repair them
Module #8	Control Problems	Figure 9 &10, Table K & App. C, cut out wiring	• identify the three main control problems on heat pumps • describe how to solve the three major problems • utilizing various wiring diagrams demonstrate knowledge of proper cut out installation

	Subject	Material	Objectives (Participants will be able to:)
Module #9	Catastrophic Duct Problems	Table C, house pressurization & depressurization, return system, boots and mechanical connections	• define a catastrophic duct problem • explain how rigid, flex and ductboard ducts should be fastened • explain why using chaseways and other building spaces as ducts is poor practice for distribution efficiency. • explain the effect on the whole house of return, supply and mixed leaks.
Module #10	Diffuse Duct Problems	Figure 8, Table C, I & J, App. I	• identify the potential leakage sites for all three kinds of duct work • explain the magnitude of the problem, including the percentage of house infiltration due to duct leaks in the pilot project • explain how rigid, flex and ductboard ducts should be sealed
Module #11	Testing Air Flow	App. C, ammeter, voltmeter, digital thermometer	• illustrate where the thermocouple probes must be placed • demonstrate knowledge of the effect on air flow calculation and COP if probes are incorrectly placed • fill out the air flow test form completely • identify how to clean the indoor coil

	Subject	Material	Objectives (Participants will be able to:)
Module #12	Customer Interaction	Review, role play interactions with the customer	• demonstrate understanding of the importance of engaging the customer as an ally • explain the need for changing the filter • explain the need to keep registers open.

	Subject	Material	Objectives (Participants will be able to:)
Module #9	Catastrophic Duct Problems	Table C, house pressurization & depressurization, return system, boots and mechanical connections	• define a catastrophic duct problem • list three areas with high catastrophic leakage potential • explain how rigid, flex and ductboard ducts should be fastened • explain why using chaseways and other building spaces as ducts is poor practice for distribution efficiency. • explain the effect on the whole house of return, supply and mixed leaks.
Module #10	Diffuse Duct Problems	Figure 8, Table C, I & J, App. I	• identify the potential leakage sites for all three kinds of duct work • explain the magnitude of the problem, including the percentage of house infiltration due to duct leaks in the pilot project • explain how rigid, flex and ductboard ducts should be sealed
Module #11	Testing for Duct Leakage	App. D, blower door and flow hood operation, pressures in the ducts	• explain what happens if a register is not covered during the flow hood test • identify the location and magnitude of the desired test pressure • demonstrate the ability to fill out the duct test form completely

IV Summary

This training plan is part of an integrated system of procedures and controls. Without the necessary feedback, inspection, and control these first few days of instruction will be rapidly lost under the pressures of production. When the program is conscientiously applied it should reduce high bill complaints, reduce customer dissatisfaction and reduce fuel switching. The program provides net lifecycle benefit to PG&E, and an opportunity for improved relations with heat pump customers.

Appendix L

Procedure Manual

Procedure Manual

This procedure manual covers work on the heat pump (FORM HP) and work on the ducts (DUCT WORK FORM). This procedure manual further explains these two forms.

FORM HP is used by the heat pump service technician when inspecting and servicing the customer's heat pump. It is a flow path/decision map of instructions to be followed sequentially by the technician.

The procedures listed here are a systematic review and testing of the heat pump. They are not the same as those used for a common complaint driven service visit. The program addresses hidden or persistent problems that regular service visits may not remedy. During a normal service call, a technician usually tries to locate the source of the complaint and fix it as soon as possible. In performing the procedures in FORM HP, a technician looks for all potential problems and checks the complete system. By this method, all components will be covered, even if there is no specific related complaint. After initial operating conditions have been measured and recorded, repairs and adjustments can be initiated. The repairs follow standardized procedures and preferred practices.

All applicable information should be entered on the from or the reason for omission noted. If any data is not applicable or unavailable the technician must state why this is so.

DUCT WORK FORM is used by the duct service technician when inspecting and repairing the customer's duct system. It too is a flow path/decision map of instructions to be followed sequentially by the technician.

FORM HP

Site Identification and General Information

Essential information about the site and occupants is recorded in this section This is very important for proper analysis.

Homeowner ______________________

Address ______________________ City ______________________

Zip Code __________ Home Phone ______________ Work Phone __________

Number of Stories ____________ Crawlspace?________ Attic? __________

Is there a crawlspace? Is there an attic?

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

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

Record fires per week (Daily = 7, one per month = .25)

Number of occupants:

Adults	Teenagers	Children

Technician______________ Date __________

1. INITIAL INTERVIEW:

THIS INFORMATION IS EXTREMELY IMPORTANT. Lifestyle and homeowner operation of the heat pump are important factors in determining energy use. This interview determines how the heat pump is used and perceived, gives critical information for diagnosis, and sets the expectations for the visit.

To start the interview, inform the homeowner purpose and procedures of the program. "PG&E has noticed that some residential heat pump customers are not obtaining the higher efficiencies that heat pumps are capable of and therefore have high bills. The program is designed to remedy problems that other service companies have not found or have not fixed for the customer. The operation of the heat pump will be checked by conducting a set of standardized tests which will determine if any of the major heat pump components is causing a lowered efficiency.

Record any comments by the homeowner about his attitude or the neighbors about heat pumps. Give the Homeowner a copy of PG&E's "How to Live with a Heat Pump"

Any problems with the system DURING THE HEATING SEASON.______________________

____

Examples: Master bedroom too cold, runs all the time, costs too much, etc.

Any problems with the system DURING THE COOLING SEASON.______________________

____

What is the approximate age of the heat pump? ________yrs.

Have you had a visit by a heat pump service technician to check your heat pump?______

When?__________ Who? ______________________________

Even a vague notion of company name or location

What did they do?____

Get as much detail about the visit as you can. Some customers will have actual service records. Especially note if the heat pump has been recharged with refrigerant and if the leak was also fixed.

Who manages the thermostat?______________________ Does anyone else in the house manage it differently? ____________________________ How?________________

You are determining if two people in the house are setting the thermostat up and down

Do you "set back" your thermostat at night or when you are away from home each day?______

Approx. T-stat settings: "Normal"_________ Night __________ Away from home ______

Are you convinced that they know how to set it up without getting strip heat?

Do you know where your system filter is? ___________

How often do you change it? __________

Many customers will change the filter just before a service person arrives, so do not take a clean filter as a sign that the customer is conscientious about changing the filter.

Do you have any paperwork on the Heat Pump?_________ If yes could you get it for me now?

This information will help you charge the unit properly if that is needed.

Check and record indoor temperature ____________

HEAT PUMP INSIDE UNIT FAMILIARIZATION & PREPARATION

2. Record from nameplate: Manufacturer _________ Model _____________

3. Duct Location____

Attic, crawlspace, chase, etc. Be specific and complete. Especially note if the duct work runs through unconditioned space or if any portions are not accessible.

4. Install digital thermometer to measure delivery and return temperatures. **THIS MUST BE SOMEWHAT DISTANT FROM THE HEAT STRIPS.**

If the thermometer can "see" the strip heaters then a false reading will result. To determine this ask yourself if you looked toward the strip heater from inside the duct work where the thermometer is to be located if you would see the strip heaters or the reflection or light from the strip heaters. If the answer is Yes then move the thermometer to a different location. The radiant energy given off by the strip heaters can cause the thermometer to read a temperature that is much higher than the actual air temperature.

Electronic digital thermometers should be checked to assure reasonably accurate readings. Good quality electronic thermometers capable of reading two locations are needed.

5. Install amp-clamp to measure current to the heat strips.

Note if the power is for the heat strips only or if includes one or more of the fans. Also be aware of any time delay between stages of the strip heaters.

THERMOSTAT INFORMATION AND FIRST CYCLE **PREREAD**

6. Is the thermostat location bad enough to warrant relocation? _____ If so record why

____

If the thermostat is in the direct airstream of a delivery register or where the sun will hit it, or where it does not sense the critical temperature of the house, it must be moved.

7. Thermostat Type: Single Stage ___ Two Stage______ Programmable HP _____

A standard heat pump thermostat has two stages of heat and no setback. A programmable heat pump has a method of recovery from set back that uses a compressor only.

8. Check thermostat: Setting ____°F Set back _____ from_____ to ____, is clock ok?_____ anticipator settings #1______#2______

Example: Setting 72°F; set back 3°F from 10p.m. to 4a.m.

9. Start heat pump by activating **ONLY** the first stage with thermostat. Check and record if there is current to the strip heaters. __________ If furnace doesn't turn on, **STOP! Contact Supervisor and tell Client.**

The wiring of the strip heaters to the first stage of heating is a big problem when it occurs. If there is current to the strip heater the thermostat is miswired. If no heat is delivered, the heat pump was inoperable before you got there; the program is not responsible.

10. Set the thermostat down. **FROM THIS POINT ON THE HEAT PUMP CAN BE CONTROLLED AT THE THERMOSTAT OR AT THE TERMINAL BLOCK.** The next test will be on emergency heat (heat strips) only.

HEAT PUMP OUTSIDE UNIT FAMILIARIZATION & PREPARATION

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

Use a calibrated thermometer where the air is sucked into the outdoor coil

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

Example: under a deck, in an inset into a wall, etc.

13. If the homeowner reports that a service technician recently added to the charge, check for leaks now.

14. Record from nameplate: Manufacturer _________ Model _____________

15. Look up the rated heating delivery ______ and EER __________

Use the Carrier Blue Book or equivalent

16. Convert heating delivery to tons (btu)_____/12,000 = ______ Tons

17. Locate where you will read the voltage to the compressor.

The preferred location is at the breaker for the outside disconnect.

18. Locate where you will put the amp-clamp to measure current to the compressor.

The two legs may have different ampere readings and both of them should be measured.

INITIAL OPERATION - AIR FLOW TEST **PREREAD**

Low air flow is the most common problem with heat pumps in the field.

NOTE THAT THESE TWO TESTS ARE TIMED - IT IS ESSENTIAL THAT THE READINGS BE TAKEN AT THE TIME SPECIFIED.

19. Start the heat pump in the emergency heat mode and start your watch to measure times.

If the thermostat does not have an emergency heat switch, the wire to the compressor relay can be disconnected and the unit put on second stage heating or the unit can be controlled by jumping the controls outside.

20. At EXACTLY 5 minutes record the first return temperature ______

Use the same location for this measurement and the ten minute measurement.

CALCULATIONS

31. AIR FLOW

Strip Heater _______ Amps. X ________ Volts = ________ Watts

The strip heaters are a pure resistance load and operate at 100% power factor. The wattage is therefore equal to the amperes times the volts. The technician should check to see if any other equipment, especially the fans are operating with the strip heaters. It is acceptable for the inside fan amps to be included in the calculation. Note if the inside fan is included.

Air Flow (_______ Watts / _________ ΔT) X 3.16 = __________ CFM

Since the energy input into the air flow is known, the flow rate can be found by dividing by the heat capacity of the air and using appropriate conversion factors.

$\frac{B}{A*C}$ = 3.16, where:

A Heat capacity of air 0.018 Btu /°F ft^3
B 3.413 Btu/kWh
C 60 ft^3 per hour / 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.

The correct air flow through the indoor coil is between 425 - 450 CFM per nominal ton. (Note: Due to the additional resistance of the wet indoor coil in cooling, this setting with the dry coil should provide the correct air flow of 400 ft^3/min per nominal ton in cooling.)

32. OUTPUT

(_______ Strip Watts / ________ ΔT Strip) X ________ ΔT Comp. = _________ Watts

Knowing the strip heater output and temperature rise from strip heat only and compressor only operation, the output from the compressor stage can be calculated.

33. APPARENT INPUT

Compressor _______ Amps. X ________ Volts = _______ Watts

The wattage is the volts times the amps. When analyzing alternating current which has a constantly changing voltage and amperage, it must be remembered that the wattage is the instantaneous voltage times the coincident amperage. On motors such as a compressor, the voltage and amperage peaks do not occur at the same time. The peak of the ampere flow occurs after the peak of the voltage. The compressor amperes and volts as measured at the compressor do not directly yield the wattage of the compressor. The ratio of the true wattage to the apparent wattage (obtained by multiplying the measured voltage times the measured amp draw) is the power factor.

34. ACTUAL INPUT

Watts from portable watt meter _____ Watts. Or from house meter clocking:

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

To clock the house meter, first ask the homeowner if it is OK to turn off the electricity to the residence. (All equipment with digital clocks will have to be reset.) If it is acceptable to the homeowner, the electricity to the rest of the house should be turned off at the circuit breaker panel. Count an integral number of revolutions on the meter while timing with a stop watch. Timing in the 30 to 60 second range is acceptable.

21. Measure and record the Amps on both legs _____/______ and Volts_______to the heat strips.

If the legs are not balanced it indicates that another load is present on the circuit in addition to the strip heaters

22. At EXACTLY 10 minutes record the supply temp ______ then the return temp ____ Disable the heat strips. Remove your amp-clamp and volt meter and take to compressor.

The temperature of the supply air can vary across the ducting. For instance the temperature at the top may be considerably hotter than the temperature near the bottom. Care should be used to insure that a representative supply temperature is obtained. The temperature should be taken at a great enough distance from the unit to insure proper mixing of the air stream, though the distance should not be so great that the air stream cools significantly.

EFFICIENCY AND OVERCHARGE TESTS PREREAD

23. Switch to compressor only heating and restart your stop watch.

The technician should insure that the compressor will not turn off during the test and that second stage is not activated. The technician can do this at the low voltage wiring strip by disconnecting the second stage and setting the thermostat all the way up.

24. Install the amp-clamp to measure the compressor current.

25. At EXACTLY 5 minutes record the supply temp ______ then the return temp ____

26. At EXACTLY 7 minutes measure and record the Amps on both legs ____/____to the compressor.

27. Record the Watts from the watt meter _____

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

See line 33-34 for a discussion of watt measurement.

28. Measure and record the Volts_______to the compressor.

29. Record the outdoor air temperature from the outside thermometer_______

The desired outside temperature is the temperature of the air entering the outside coil. In cases of recirculation because of blockage, this temperature may be different than the ambient air temperature. Since the heat pump is operating at the effective reduced temperature this is the one that should be recorded. Also the difference between the ambient and the effective outside temperature due to recirculation should be noted.

ACID AND MOISTURE TESTS

30. Perform the Carrier "TOTAL TEST" and record the results _____ Acid, ______ Moisture.

Moisture or acid in the refrigerant can rapidly lead to compressor failure. If it is present, the unit should be cleaned and recharged .

35. COEFFICIENT OF PERFORMANCE

________ OUTPUT / _______ ACTUAL INPUT = ____ C.O.P.

If the calculated COP is low compared to the manufacturer's data and the air flow is correct, an improper charge should be suspected. If the air flow is less than 425 CFM/Ton, it should be corrected first and the COP remeasured.

Result is plotted on the COP Graph. It should be above the minimum line for a heat pump with the same EER rating or EER 7.8. If it is less, we must find if the unit is incorrectly charged. Use the manufacturers method for determining correct charge if it is available, otherwise adjust charge to maximum COP, while checking head and suction pressures.

The peak COP for a given temperature may actually occur at some amount of under or over charge. For this reason using the manufacturers method of checking charge is preferable.

REPAIRS AND ADJUSTMENTS

36. If AIRFLOW is less than 400 cfm. remove restrictions and/or increase the blower speed to achieve 425-450 cfm. Record all work done________________________

37. Are there any refrigerant leaks? If so repair, evacuate and recharge with the precise charge. Record location of all leaks______

The vast majority of time that the heat pump is low on refrigerant, the problem is due to a leak. If the heat pump has been in service for a number of years and has had a number of service visits but no leaks, the small amounts of refrigerant released each time the system is checked can create an undercharged unit. Save any refrigerant removed for recycling.

38. If there is moisture or acid in the system, Inform the homeowner, Evacuate and purge the system, saving the refrigerant for recycling. Then recharge with the precise charge.

39. If COP is less than specified on COP graph, determine if refrigerant charge is incorrect. Then charge to correct charge.

If the calculated COP is low, an improper charge should be suspected. An undercharged unit is easily spotted since it will almost always have a low COP. Overcharge is somewhat more subtle. Signs of overcharge include:

- hot gas temperature is less than 100°F above ambient.
- high head pressure
- high amp draw

If the system is truly overcharged, as refrigerant is bled off, the head pressure will first fall slowly. With additional removal, a point will be reached where the suction pressure begins to drop. This is very near the correct charge.

40. Visually inspect evaporator coil, record cleanliness, and clean if dirty. ________________.

If a significant amount of the fin area is bent and blocked, this should be noted and the fins straightened.

41. Inspect filter and record condition. __________ Clean or replace the filter if dirty

42. Visually inspect blower record cleanliness and clean if dirty ____________________.

43. Oil circulation blower and motor.________________________________

44. If Defrost cycle has an initiation timer and it is adjustable and it is set at less than 90 minutes reset it to 90 minutes and record____

If the defrost timer is nonadjustable, record this and the cycle time. ________

DUCTWORK

Repair of duct work problems has been found to be the single most important and most common problem area. The high pressure of the air in the ducts means even a small leak can cause significant energy loss. Particular attention needs to be paid to disconnected ducts.

45. 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 ____

46. 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 ____

47. Visually inspect all the duct work by walking/crawling the length of it. Repair any disconnects or substantial leaks. ____

____

CONTROLS

Operation of the strip heaters for setback recovery is a major problem. The installation of a strip heat lockout can avoid this problem.

48. Unless the thermostat is a programmable heat pump thermostat with a built in ramp up feature install a new HP thermostat and record______________________________
Check out the function of your installation.

Use the existing thermostat wire. If the existing house wiring does not have enough wires to support a new thermostat, leave the existing one in place. The new thermostat will usually need eight wires.

49. Install an outdoor thermostat to cut out the strip heaters when the temperature is above 35°F. Be sure the probe is sensing the outdoor temperature and will not be in the sunlight. The cut out should not effect the control of emergency heat. Record all work done________________
Check out the function of your installation.

ALWAYS CHECK THE FUNCTION OF YOUR INSTALLATION. Stage 1- compressor heating only, Stage 2- compressor heating and strip heat, Emergency Heat - strip heat only.

SECOND TESTS - AIR FLOW TEST **PREREAD**

A second set of tests (Air Flow, and Efficiency) are to be conducted if the operation of the heat pump has been changed at all by the above work.

NOTE THAT THESE TWO TESTS ARE TIMED - IT IS ESSENTIAL THAT THE READINGS BE TAKEN AT THE TIME SPECIFIED. ALWAYS PERFORM THIS TEST UNLESS NO DUCT SEALING, COIL, FILTER OR BLOWER CLEANING HAS BEEN DONE

50. Reconnect the strip heaters. Start the heat pump in the emergency heat mode and start your watch to measure times.

51. At EXACTLY 1 minute record the first return temperature _______

52. At EXACTLY 5 minutes record the heat rise _______

53. At EXACTLY 5 minutes and 15 seconds record the second return temperature _______ Disable the heat strips.

FINAL EFFICIENCY AND OVERCHARGE TESTS **PREREAD**

54. Switch to compressor only heating and restart your stop watch.

55. Install the amp-clamp to measure the compressor current.

56. At EXACTLY 5 minutes record the heat rise _______

57. At EXACTLY 7 minutes measure and record the Amps on both legs ____/____to the compressor.

58. Record the Watts from the watt meter ______ or Watts from house meter test.______

59. Measure and record the Volts________to the compressor.

60. Record the outdoor air temperature from the outside thermometer________

FINAL CALCULATIONS

61. AIR FLOW

Air Flow (________ Strip Watts / ______ Δ T) X 3.16 = _________ CFM

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

62. OUTPUT

(_______ Strip Watts / ________ Δ T Strip) X ________ Δ T Comp. = _________ Watts

63. APPARENT INPUT

Compressor ________ Amps. X ________ Volts = _______ Watts

64. ACTUAL INPUT

Watts from portable watt meter _____ Watts. Or from house meter clocking:

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

65. COEFFICIENT OF PERFORMANCE

________ OUTPUT / __________ ACTUAL INPUT = _ **C.O.P.**

Result is plotted on the same COP Graph as used earlier. Use this to explain to the homeowner what you have accomplished.

SUBSEQUENT TESTS **PREREAD**

Subsequent sets of tests (3rd, 4th, etc.),(Air Flow and Efficiency) are used to measure the operating parameters if previous work does not correct the COP. Label the test number, record the work done to improve the system, then record the results. These are most often used when "chasing the efficiency".

Work Done on the unit and effect____

____

____

____

____

____

____

EFFICIENCY AND OVERCHARGE TESTS **PREREAD**

66. REDO AIR FLOW TEST if you have changed the airflow and record results below.
67. Start compressor only heating and restart your stop watch.
68. Install the amp-clamp to measure the compressor current.
69. At EXACTLY 5 minutes record the heat rise _______
70. At EXACTLY 5 minutes record the supply temp _______ then the return temp ____
71. At EXACTLY 7 minutes measure and record the Amps on both legs ____/____to the compressor.
72. Record the Watts from the watt meter ______ or Watts from house meter test._____
73. Measure and record the Volts________to the compressor.
74. Record the outdoor air temperature from the outside thermometer_______

CALCULATIONS

75. AIR FLOW

Air Flow (________ Strip Watts / ______ Δ T) X 3.16 =__________ CFM

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

76. OUTPUT

(_______ Strip Watts / _________ Δ T Strip) X _________Δ T Comp. = __________ Watts

77. APPARENT INPUT

Compressor ________Amps. X _________ Volts = ________ Watts

78. ACTUAL INPUT

Watts from portable watt meter _____ Watts. Or from house meter clocking:

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

79. COEFFICIENT OF PERFORMANCE

____ OUTPUT / _____________ ACTUAL INPUT = ___ **C.O.P.**

DUCT WORK FORM

DUCT WORK INFORMATION Homeowner ______________________

Address ______________________ City ______________________

Zip Code ____________ Home Phone ______________ Work Phone ____________

Inspector ______________ Date ________

Essential information about the site and it's occupants is recorded in this section This is very important for proper analysis.

Are there any portions of the house that either get too much or too little heat?____________

____

____

____

Uneven air flow may indicate blocked or disconnected ducts. Pay special attention to these areas when inspecting the duct work.

Check and record indoor temperature ________

The indoor temperature is used to calibrate the air flow to standard conditions.

INITIAL BLOWER DOOR TEST

1. Install the blower door to pressurize the house.

   The blower door is installed with the fan on the exterior of the house so the house is pressurized.

2. Close all windows and exterior doors. Be sure to close fireplace and wood stove dampers.

3. Do the first three blower door tests. Have the homeowner help you find all the registers.

   The pressure vs. air flow readings are to be taken at 5 points between 15 and 60 pascals. The most important points are at 50 pa so take a good measurement at 45 and 50 pa. Occasionally a house will not pressurize to 50 pa. If so check for open windows, doors or attic access. If it still doesn't pressurize run the series at lower pressures.

The three blower door tests are:

1) Whole house air flow with all supply and return registers open and clear
2) Whole house air flow with all supply and return registers sealed
3) Unseal and remove the filter from largest return or the return closest to the heat pump. Measure the flow through the flow hood when the house is pressurized to 50 pa with the blower door.

4. Check and record all the data on the Duct Leakage Test Form. This includes a guess at the wind speed, and the number of inches of insulation in the walls, ceiling and floor.. Shielding factor is normally 1.0, If the house is exposed without trees it is 1.2, If it is behind other buildings it is .9.