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An Ounce of Prevention: Residential Cooling Repairs

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An Ounce of Prevention: Residential Cooling Repairs

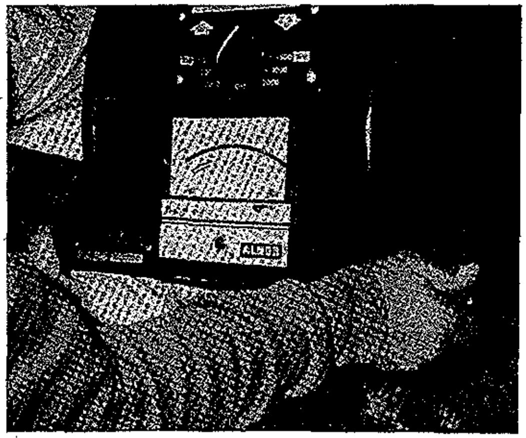
John Proctor

A Pacific Gas and Electric study of high cooling bill complaints in Fresno, California, revealed that low air conditioner efficiency could be remedied by informed diagnostic and repair techniques.

Many utilities must answer to three masters. *Customers* want reasonably priced power. *Shareholders* want a good return on their investment. And *regulators* want sound conservation stategies. Northern California-based Pacific Gas and Electric (PG&E) created the Appliance Doctor Pilot Project in 1990 to answer the needs of those three constituencies. The project's goals were to reduce electrical peak demand, save energy, and provide meaningful responses to high bill complaints.

The program hired Proctor Engineering Group (PEGrp) to investigate the potential energy and peak reductions made possible by repairing existing residential air conditioners and gas-fired, forced-air furnaces.[1] Previous studies had indicated that effective service of existing air conditioners results in substantial energy savings. For example, a 1987 field study of residential air conditioners in North Carolina found that with standard installation and maintenance, air conditioner efficiency had degraded by 30% to 40%.[2] And a 1990 PG&E project investigating the cause of high bill complaints from heat pump customers revealed that energy savings of 27% and significant peak electrical load reduction were possible from a well-controlled repair and maintenance program which included strong quality assurance and technician training.[3]

John Proctor is president of Proctor Engineering Group in San Francisco and the author of many residential heating and cooling efficiency studies.



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This flow hood placed over the return grill demonstrated a sizable air leakage reading due mainly to a faulty duct system.

Finding The Problems

PG&E selected Fresno for the pilot project because of its weather conditions, giving that locale high cooling loads for the service area. The location features 1769 cooling degree-days and 2647 heating degree-days annually (65°F base). Fifteen homes were selected for the study. The majority belonged to customers with high summer peak loading and with complaints of high utility bills. Their average cooling use (3658 kWh) was more than double the Fresno residential average (1650 kWh). PEGrp thoroughly tested each home's air conditioner, building shell, and ductwork to determine the mechanical cause of the high bill complaint. Deficiencies were repaired and each unit retested to confirm that the repairs were effective.

Measuring The Effects of Repairs

We used submeters to record the air conditioner kWh consumption for every 15-minute period, both before and after repairs were made. The data was analyzed to determine the peak electrical load for each house and to identify how the residents adjusted their thermostat controls.

While two participants no longer used their air conditioners because they felt their bills were too high, almost half of the remaining sites used the *off/on* air conditioner control manually, switching the air conditioner *on* to make it cooler and *off* when it was cool enough.

Most Common Problems

We traced customer bill complaints to problems with the distribution system, the appliance, and the building shell. Ten of the fifteen units had been serviced within the last two years by local contractors who failed to identify or resolve these deficiencies. Two individuals had service agreements with local contractors who inspected the units twice a year. While one of these houses had the most efficient air conditioner in the study, it also had two disconnected supply ducts which had never been detected. Our inspection of the second unit found it to be 20% low on refrigerant at the time of the study. Because there were no refrigerant leaks, it's possible that the missing refrigerant was allowed to escape during the twice-yearly checkups. Table 1 provides a breakdown of all problems identified in the study and their frequency of occurrence.

Table 1. Fresno Appliance Doctor Project: Major Deficiencies And Rates of Occurrence

	Percent with Problem
AIR CONDITIONER PROBLEMS:	
Airflow less than 375 cfm/ton* (dry coil)	67%
Coil Dirty or Clogged	53%
Filter Dirty, Clogged, or Missing	40%
Overcharge (Avg. 10% Excess Charge)	27%
Undercharge (Avg. 20% below Correct Charge)	27%
Refrigerant Leak	20%
Other (Kinked Lines, Wrong Capacitor, etc.)	20%
DISTRIBUTION PROBLEMS:	
Duct leakage greater than 150 cfm	93%
SHELL PROBLEMS:	
House Leakier than 0.75 Natural Air Changes/hr.	33%
No Wall Insulation	93%
Ceiling Insulation, Less Than R-11	27%
Ceiling Insulation, R-11 to R-18.9	13%

* Cubic feet per minute per ton of air conditioning

Energy Savings Estimates

Based on the data collected from submetering during this project and past studies, the anticipated energy savings and peak reduction for individual repair measures are shown in Table 2. The predominent effect of field repairs on the air conditioners was to bring airflow and refrigerant charge to near their designed state. As a result, the largest efficiency improvements occurred on those air conditioners we found operating furthest from their design parameters.

Table 2. Fresno Appliance Doctor Project: Savings And Peak Reduction Estimates For Individual Repair Measures

Repair Measure	Cooling	Kw Peak* (Watts)	Heating
Correct Low Airflow	8%	100	2%
Repair Overcharge	12%	310	
Repair Undercharge	12%	180	
Repair Duct Leakage	18%	530	12%

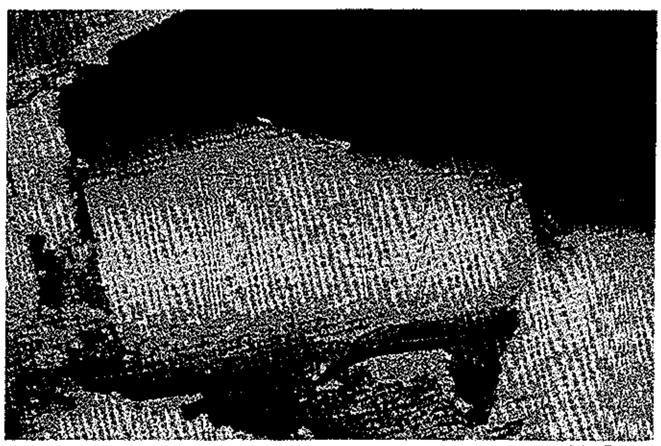
*Based on data from submetering

Low Airflow: A Major Problem

Low airflow in all the homes averaged 350 cubic feet per minute per ton of air conditioning (cfm/ton). Airflow was measured in two ways, by the temperature rise test and by the flow hood method. The temperature rise method is based on putting a known amount of energy into the air stream. This was accomplished by turning on the furnace. The mixed supply temperature—used to calculate the energy input—and the mixed return temperature were measured. A single calculation, based on the heat capacity of air, determined the airflow necessary to achieve the measured temperature rise for the known input. It should be noted that this method may not be appropriate outside of research activities because of time constraints (the furnace must be on at least 20 minutes for accurate readings) and occupants' objections to having their homes heated in the summer.

The flow hood method utilized a commercial flow hood to measure the flow at each register. The flows from all the returns and the return duct leakage were summed for the total flow.

Our measurements showed that low airflow was the most prevalent deficiency in air conditioner preformance and the second most common problem overall (after excessive duct leakage). Fully two-thirds of the units studied had low airflow. Airflow across a dry coil should be 425 to 450 cfm/ton to provide the correct level of airflow (400 cfm/ton) through the unit when the air conditioner is running and the coil is wet.



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This gaping disconnection in the ductwork cancels out many of the benefits of an otherwise tightly built home.

Measuring The Energy Efficiency Ratio (EER)

Calculating the efficiency of air conditioners is a process which measures three items:

- airflow through the inside coil;
- change in wet-bulb temperature across the coil; and
- electrical input to the unit after it has run for 15 minutes.

Before you begin, it's important to inform the occupants of the household that you will need to cut their power for up to a half hour. Some individuals depend on power for life support, so be certain to check first.

Step One—Examine and Prepare The Air Conditioner

Inspect the air conditioner and determine its manufacturer and model number. Use this information to look up the unit's rated capacity (tonnage) and EER in the Carrier "Blue Book" (the vast majority of existing air conditioners are listed). The listed capacity in Btu/hr, divided by 12,000, is the capacity in tons.

You will be testing the wet-bulb temperature in the supply and return ducts near the inside coil. The wet-bulb temperature can be measured using a standard thermocouple probe with a wet piece of cotton shoelace secured over the thermocouple junction. Using a dual-point digital thermometer, place one probe in the center of the air stream in the return duct and another in the center of the airstream in the supply. Both probes must be placed so they sense the mixed air.

Step Two—Measure The Airflow

Measuring the airflow is relatively straightforward on heat pumps (see "Measuring Heat Pump Efficiency," *HE* Mar/Apr '91, p. 33), but slightly more difficult on air conditioners. The easiest method is to use a commercial flow hood which compensates for the restriction through the flow hood itself.

Switch off all circuit breakers except the one to the air conditioner. Check the house electric meter to ensure that the meter is not moving. Adjust the thermostat to its coldest setting and start your stopwatch. (You did remember your stopwatch, didn't you?) At that time the inside fan should come on. If it doesn't, the fan is on another circuit breaker. (This is common on "split" systems where the inside fan and coil are in a separate unit from the compressor—usually at the furnace.) If the fan doesn't start, turn on the circuit breaker to the furnace.

The coil should be wet. Run the air conditioner for ten minutes. Record the inside temperature while you're waiting. If you have a sling psychrometer, record both wet and dry bulb temperatures. At ten minutes, use the flow hood to measure the airflow at every return register. When you add these figures to the leakage into the ducts before the coil, in cubic feet per minute (cfm), you will have the flow through the unit. (We strongly recommend measuring the return leakage using the flow hood method. If for some reason you don't, assume approximately 200 cfm of leakage occurs between the registers and the coil.) The resulting airflow should be approximately 400 cfm/ton.

Step Three—Measure Temperatures And Input

At 15 minutes, record the wet-bulb temperatures in both the supply and return plenums. This simplified method allows calculation of the air conditioner's total cooling capacity. Also record the outside temperature now; it has a large effect on the EER. Additional tests can determine the amount of sensible cooling (lowering the temperature) and latent cooling (removing moisture).

Immediately following the wet-bulb measurements, clock the revolutions of the house meter and record:

- meter Kw (on the meter face—usually 7.2),
- number of revolutions (at least ten), and
- time for those revolutions (seconds).

(That stopwatch is handy, isn't it?)

Step Four—Calculate The EER

Get the ASHRAE Fundamentals or a manufacturer's training handbook and look up return and supply enthalpy based on the return and supply wet bulb measurements you've made.* Subtract the supply from the return enthalpy to get the change in enthalpy. The total output is then calculated as:

cfm x change in enthalpy x 4.5 = capacity (Btu/hr)

The input is calculated from the meter reading:

# of revolutions x Kw x 3600/# of seconds = input (watts)

The Energy Efficiency Ratio (EER) is:

capacity/input = EER (at test conditions)

Remember, the listed EER is for the following conditions:

- airflow 400 cfm/ton,
- outdoor temperature 95°F, and
- indoor temperatures of 80°F dry-bulb and 67°F wet-bulb.

Cooler outdoor temperatures or warmer indoor temperatures will raise the EER.

* Use "Table 1, Thermodynamic Properties of Moist Air, Standard Atmospheric Pressure," *ASHRAE 1989 Fundamentals Handbook*, I-P edition, pp.6.2–6.5. Or "Table 1, Enthalpy at Saturation, Btu per pound of dry air," *GTA-3A Advance General Trainings: Air Properties & Measurement*, Carrier Corp., 1978, p.54.

The principal cause of low airflow is a dirty inside coil, and the most effective repair method is to clean it. One coil was so dirty and wet that mold had grown on it. An air conditioning technician had visited the house recently to diagnose the problem. He correctly diagnosed low airflow, but rather than cleaning the coil he sold the homeowner a higher-horsepower motor for her indoor fan.

Other causes of low airflow include clogged filters and closed registers. At one study house, the filter had not been changed for over a year and only two of its ten delivery registers were fully open. Of the eight registers that were misadjusted, four were completely closed and four partially closed. Most air conditioning technicians do not regularly test for airflow. Indoor coils are often accessible only with extreme perseverance, decreasing the likelihood that they will be examined or cleaned. Crushed and kinked ducts, another cause of low airflow, are not usually repaired since technicians do not regularly work on ducts.

With belt-driven blowers, incorrectly adjusted drive pulleys are a common cause of low airflow. An effective repair measure is to adjust the pulley to produce a higher blower speed.

Cleaning the coil, opening registers, and/or adjusting the drive pulleys increased airflow by 16% in the ten deficient units.

Improper Refrigerant Charge

Over half the units (eight) had improper refrigerant charge, with equal numbers having under- or overcharge. The average amount of incorrect charge was 10% for overcharge and 20% for undercharge. In the field, most technicians make the determination of proper refrigerant charge through guesswork. This causes the

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compressor to run longer (undercharge) or to work harder (overcharge) as well as compressor failure and comfort problems. Proper testing of refrigerant charge is a straightforward procedure (See " 'Superheat' Method," below).

Refrigerant leaks are common and often go unrepaired. One unit under a service contract providing yearly visits had multiple deficiencies (including furnace problems which posed a potential threat to the health of the occupants). PEGrp found three leaks in the air conditioner's inside coil and leaks at both Schrader valves. The contractor had installed two pounds of refrigerant at the end of June. When we inspected the unit just two months later one and one-half pounds had escaped. This unit clearly required replacement, but the contractor's advice to the owner of the unit was to add refrigerant at the beginning of every summer.

Duct Leakage: A Hidden Culprit

Duct leakage was the most prevalent energy waste problem, occurring in all but one of the homes studied. PEGrp and other researchers estimate that average leakage can be limited to 150 cfm at 50 Pa in existing housing stock. We found the average initial duct leakage in the houses in our study was 419 cfm (corrected to 50 pa pressure), more than twice the realizable level. Results of flow hood duct leakage tests are shown in Figure 2.

Duct leakage comprised 15% of the total house leakage. However, the effect of this leakage was much larger than the percentage implied. The highest pressure differential across leakage sites occurred at ductwork cracks when the inside fan was on. For homes in the study, these pressures occurred during 30% of the cooling hours.

Leaks in the supply ducts expel air that is cooled below house air temperature. A 10% supply duct leak to the outside is a 10% cooling capacity loss. Superheated attic air leaking into the return system further increases the

'Superheat' Method For Determining Air Conditioner Charge

The most common types of air conditioners utilize capillary tube flow control. The "superheat" method of checking charge may be used for this type of unit whenever the outside temperature exceeds 70°F. The superheat measurement can determine the correct or incorrect charge using only a dual-point digital thermometer.

Step One—Install Thermocouples

Put a thermocouple, attached to a device that reads within 2°F, into the area of the cold (inside) coil, placing it in contact with the tubing halfway up the edge of the coil. Insulate the thermocouple to ensure an accurate reading. Place and insulate a second thermocouple on the suction line (the large line from the inside coil to the compressor). The sensor should be placed just before the accumulator on package units and a little before entering the outside cabinet on split units. The test must be run with all the panels in place, so be sure to replace any panels removed while installing the thermocouples.

Step Two—Measure The Energy-Efficiency Ratio (EER)

For this procedure, see "Measuring the Energy Efficiency Ratio (EER)," on p. 25. Measuring the EER prepares the air conditioner for the charge test in three ways. First, it determines the airflow through the unit. (Note: If the airflow is less than 350 cfm/ton, the superheat test will not give meaningful results.) It also indicates whether there is a need to check for incorrect charge. Finally, it brings the system to equilibrium conditions which are necessary for the test. When the efficiency test has been completed, leave the air conditioner running to measure the superheat.

Step Three—Determine Superheat

Record indoor and outdoor dry-bulb temperatures. These will be necessary to interpret the the superheat results. Measure and record the suction line temperature and the cold coil saturation (middle coil) temperature. The difference between these two readings is the superheat.

Step Four—Determine State of Charge

Look up the correct superheat in Figure 2. The unit is charged properly when the measured superheat is within 5°F of the correct superheat. If the unit is overcharged, the superheat will be more than 5°F low; if it's undercharged, the measured superheat will be more than 5°F above the correct level.

Example

Suction Line Temperature	59°F
Cold Coil Saturation Temperature	42°F
Actual Superheat (59°F minus 42°F)	17°F
Outdoor Dry-Bulb Temperature	95°F
Indoor Dry-Bulb Temperature	80°F
From Figure 2, Correct Superheat	14°F

Since the actual superheat is within 5°F of the correct superheat from the chart, the unit is charged properly. Adjusting the charge should be attempted only by thoroughly trained individuals.

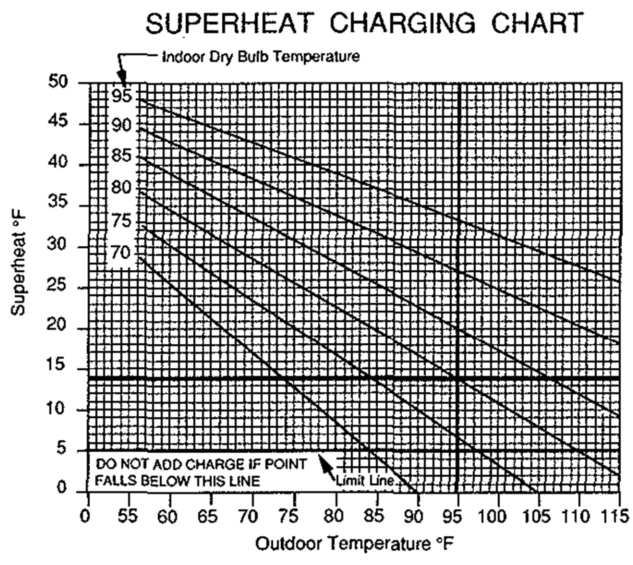
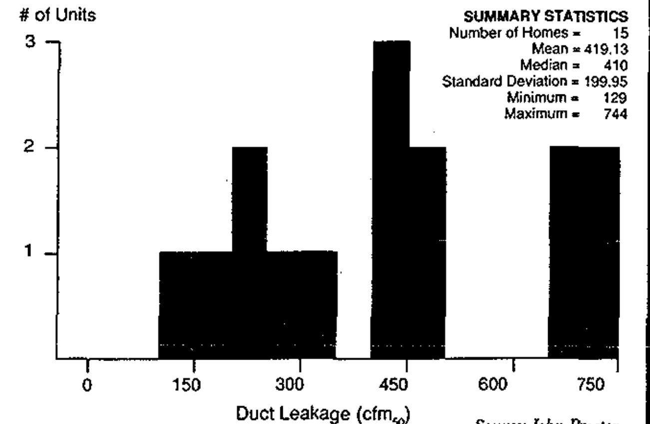


Chart based on 400cfm/ton indoor airflow and 50% relative humidity.

Source: From "Service Procedures Weathertron Heat Pump," Fig. 720-1, p. 32, The Trane Co., Pub. No. 22-8073-1.

Figure 1. The superheat charging chart for adjusting refrigerant charge.

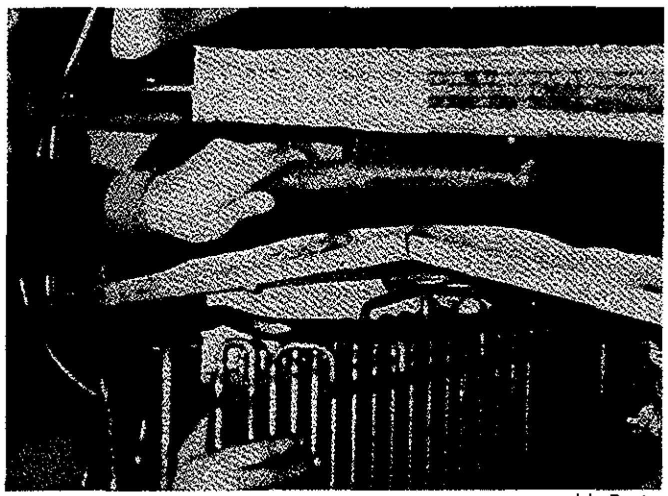


Source: John Proctor

Figure 2. Results of flow hood duct leackage tests.

cooling load. Duct leakage caused an increase in the average cooling load of approximately 25%. (Incidentally, the corresponding heating loss was 16%).

The occupants of one house reported that one register didn't deliver any air. Our investigation showed that the ductwork was disconnected from that register and was stretched over toward a new register in an addition. The disconnected duct ended up not being attached to either register, dumping its conditioned air into the attic.



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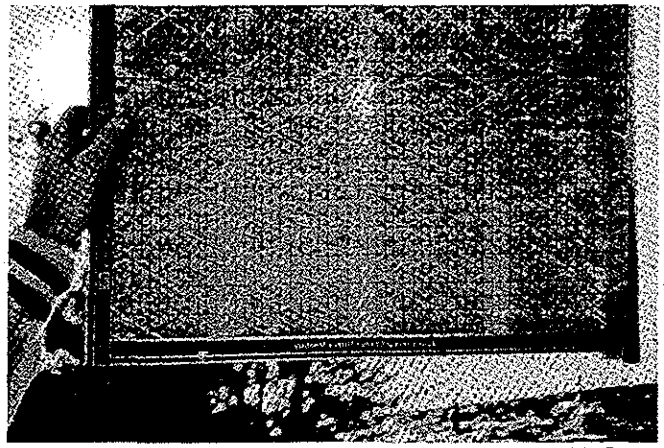
An inside coil is cleaned with a wire brush.

Effectiveness of Duct Leakage Repairs

After an initial learning period during the Appliance Doctor Project, technicians were able to eliminate almost 60% of the measured duct leakage. With proper training and feedback, it's possible to spend four hours of work sealing ducts and achieve an average 65% reduction in leakage. Work by John Tooley in Florida produced an average reduction in duct leakage of 67%.[4] Technicians do not normally conduct duct repairs; however, they could play a major role in reducing energy loss from this source.

In a number of instances, the location of the duct leak could be determined but was inaccessible for repair. The highest electric user in the study (with summer electric bills of over $400 per month) had large return and supply duct leaks. The returns were entirely accessible in the attic, but the supplies dropped through inside walls, ran between floors, and traversed a crawlspace only slightly larger than the ducts themselves. The leaks in the walls and between the first and second floors were inaccessible and could not be sealed. Two partial disconnects were evident in the crawlspace, but repair would have required removal and reinstallation of four duct runs.



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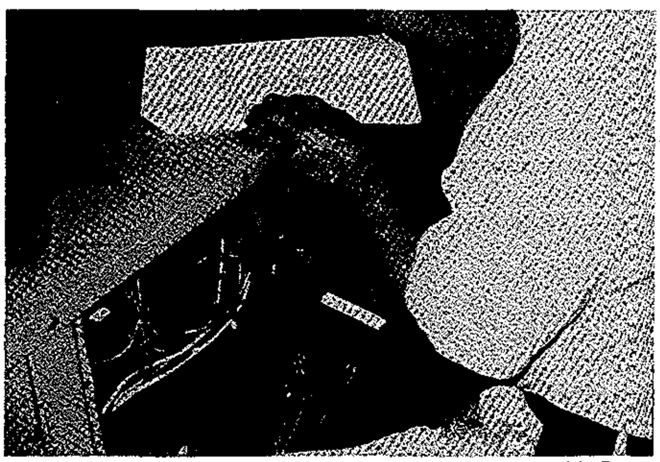
The sun can barely shine through the dirt build-up on this air filter. Replace those filters regularly!

Building Shell Deficiencies

Excessive air infiltration was the most common shell problem in the homes studied. We used a blower door to measure air infiltration, using a base of $cfm_{50}/20$ for our calculations. The natural air change estimate averaged 0.68 air changes per hour (ach), well in excess of the California Energy Commission's assumed standard of 0.5 ach.

All but one unit lacked wall insulation and six had ceiling insulation of R-19 or lower. This was due in part to the age of the structures. Only one unit was built after California's Title 24 standards were in place. Many also had inadequate attic ventilation for the climate.



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A step-by-step diagnostic procedure—instead of "winging it"—helps the serviceperson evaluate the system and determine the next step.

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Conclusion

The PG&E Appliance Doctor Pilot Project has identified a significant source of untapped electrical savings and electrical peak reduction in the use of repairs to bring existing cooling equipment to design performance. (Similarly, gas savings will result from the project's repair component.) Field testing has proven that these repairs are economically feasible and provide a substantive response to customers with high bill complaints.

PG&E is currently planning a production program based on this study to diagnose and repair duct leakage, low airflow, and overcharging in residential air conditioners. Three thousand homes characterized by high cooling energy consumption will be selected for service and repairs to air conditioning systems in 1992. The utility will fund the tight administrative control necessary and provide a 75% rebate of the on-site costs. Table 3 summarizes the projected savings, costs, and benefits of the program to those homes characterized by high cooling energy use.

Table 3: Projected Program Savings and Costs
(including interactive savings effects)

Average cooling energy savings	24%
Average coincident peak reduction	690 watts
Average heating energy savings	12%
Average utility cost	$310
Average utility net lifecycle benefit[1]	$1030
Participant cost	$50 to $90
Average participant net lifecycle benefit[2]	$1549

1. Net benefit is gross benefit minus cost.
2. Participant net benefit does not include effect of the rebate.

Importance of Program Control and Feedback

A common theme in all phases of this project was the need for increased program control and feedback. Major deficiencies in most of the homes studied had been neither identified nor resolved. Our study concluded that contractors do not sufficiently audit the effectiveness of diagnostic and repair activities by technicians whose work is not usually inspected at the site nor is their documentation reviewed. It's important that problem diagnosis and repair measures be verified by program managers, and that the results of repairs be documented and passed on to technicians.

Contractors must be motivated to bring appliances up to their full operating efficiency. In an industry based on least cost/lowest bid incentives, there is little incentive to invest the time needed for effective diagnosis and repair. The expectations placed on field technicians for productivity and revenue generation create tremendous pressure to get in, do the job, and get out—fast. While technician training is a worthwhile goal, this training must be accompanied by adequate time to complete each job properly and by feedback on the results of their work. Unless these measures are taken, major problems are likely to continue to go undetected and/or unrepaired. ■

Recommended Criteria for New and Replacement Air Conditioner Installations

Based on the Fresno air conditioning study and the previous PG&E heat pump study, Proctor Engineering Group has proposed that strict criteria guide new and replacement installations. The only assurance that the units have been installed properly is an in-house test of the unit and its ductwork. The recommended criteria are:

1. The measured airflow must be between 5% below and 15% above the manufacturer's specification.
2. The installed Energy Efficiency Ratio (EER) must be tested on site and be within 10% of the manufacturer's specification for the conditions at the time of the text.
3. The inside coil and filter must be accessible for cleaning.
4. For new construction, the size of the unit must not exceed the size specified from Manual J calculations.
5. For replacement units, the new unit must be of the same size or smaller than the existing one.
6. For new construction, the ductwork must be sealed with mastic at every joint. The duct leakage should be tested and known to be less than 150 cfm at 50 Pa house pressure.

Notes

1. Proctor, John, "Pacific Gas and Electric Appliance Doctor Project," Summer 1990. The full report is available for $15 from Proctor Engineering Group, 45 Massasoit St., Suite 102, San Francisco, CA 94111.
2. Neal, L., North Carolina Alternative Energy Corp., "Residential Air-Conditioning Field Performance Status and Future Priorities," ACEEE Summer Study on Energy Efficiency in Buildings, Vol. 4, Summer 1988.
3. Jenkins, Virginia, "Heat Pumps: Tricks of the Trade That Can Pump Up Efficiency," *Home Energy*, Mar/Apr '91, pp.29–34.
4. Cummings, J. B., Dunsmore, R., Moyer, N., Tooley, J. J. Jr., "Impact of Duct Leakage on Infiltration Rates, Space Conditioning Energy Use, and Peak Electrical Demand in Florida Homes," ACEEE Summer Study on Energy Efficiency in Buildings, Vol. 9, Summer 1990.