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SCE Coachella Valley Duct and HVAC Retrofit Efficiency Improvement Pilot Project

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ABSTRACT

In 1994, Proctor Engineering Group investigated opportunities for improving air conditioning system performance in existing houses in Southern California Edison's service territory. This investigation involved field testing duct systems, air conditioners, and building shells in 30 houses; hiring and training contractors to repair duct leakage and correct deficiencies in air conditioners; and detailed modeling of the energy and peak demand impacts from these improvements. The investigation found substantial deficiencies in most of these systems. Duct leakage caused an average effective capacity loss of 35% (44% under peak conditions). Air conditioners often had insufficient air flow across the indoor coil and could not be brought to the correct amount of air flow without substantial modification of the duct system design and/or sizing. The improvements made by contractors led to substantial reductions in duct leakage and improved air conditioner performance in most houses. The retrofits are predicted to provide significant energy and peak demand savings while improving occupant comfort and satisfaction.

EXECUTIVE SUMMARY

Southern California Edison (SCE) contracted with Proctor Engineering Group (PEG) to investigate opportunities in the Coachella Valley area of SCE's service territory for improving air conditioning system performance residential customers houses. This investigation has involved field testing the duct systems, air conditioners, and building shells in a sample of houses of customers with high summer seasonal energy usage; assessing achievable improvements to the systems through application of repair technologies; and analyzing the potential energy savings and peak demand reductions from the improvements. The investigation found that customer homes in the Coachella Valley area have substantial deficiencies in their cooling systems. The duct leakage problems in these homes exceed those found in studies from other parts of the country and other parts of California (44% leakier than existing systems in Fresno, California). Air conditioner problems are similar to those found in other studies (only one of the systems had the proper air flow, refrigerant charge, operating capacity and EER when first tested). Appendix A contains brief descriptions of related studies. Coachella Valley homes fall roughly into two categories, homes where effective repairs can be made at moderate cost, and homes where ducts are difficult to access and repair costs will be high.

The key findings of this study include:

- Houses must be visited and screened for combustion safety or accessibility problems that preclude inclusion in the program (31% of the homes failed the combustion safety screen and 43% of the homes had insufficiently accessible ducts).
- Duct leakage and existing duct insulation levels cause an average loss of 49% in overall cooling efficiency.
- Existing duct systems in pilot homes have an average efficiency loss at peak of 62%.
- The effectiveness in sealing ducts was dependent on the contractor used.
- In homes that have accessible duct work the modeled cooling energy savings from the repairs in this pilot averaged 22% using the most effective contractor. The average cost of these repairs was $615 ($375 for ducts and $240 for AC repairs).
- Using the most effective contractor the modeled diversified peak reduction under baseline assumptions is 0.46kW at system peak and 0.49 at residential peak.
- With the most effective contractor, the effective capacity (cooling capacity actually delivered to the house) of the air conditioners was increased by an average of 60% under peak conditions.
- Customers were highly satisfied with the program (95% rated the program as good or excellent) and 45% indicated a willingness to pay for the service.

Southern California Edison has a potentially worthwhile option for improving cooling efficiency, reducing peak demand, and increasing customer comfort. Proper program design, contractor selection, training, and quality assurance are critical issues for actually achieving these improvements.

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BACKGROUND

Southern California Edison (SCE) contracted with Proctor Engineering Group (PEG) to assess the potential energy savings and peak demand reductions achievable from a duct and air conditioner efficiency improvement program targeted to houses in the Coachella Valley. This region has the largest concentration of high use customers and has the largest HVAC contribution to system peak of any area in SCE's territory. A pilot project was designed and implemented with the goal of developing a production method to reduce cooling energy usage by 20% in these high use houses. The project involved five steps:

- determine the causes for high usage in 30 identified houses through direct field testing of air conditioners, ducts and building shells;
- repair the duct and air conditioner problems identified;
- re-test the homes to ensure effective repair;
- compare two alternative production methods for delivering repairs;
- perform a detailed engineering analysis of the field data to estimate the impacts of the improvements on energy usage and peak demand.

This report describes the activities and results from the pilot project.

Prior Research

PEG's prior experience, and the findings of other research projects around the country (see Appendix A), has found that air conditioning systems in high energy usage customers houses usually have numerous problems which adversely impact efficiency, demand, and comfort. The primary problems identified include:

- excessive duct leakage in unconditioned spaces leading to substantial loss of conditioned air, heated return air, and increased house infiltration;
- inadequate insulation on duct systems located in unconditioned spaces;
- insufficient air flow across the indoor coil;
- incorrect refrigerant charge;
- diminished operating capacity and efficiency.

In prior studies, these problems were found to be common, not unusual, circumstances. Duct leakage has become a significant concern in the recent past. Studies from California, Florida, and the Pacific Northwest have consistently found large efficiency losses due to typical levels of duct leakage.

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PILOT PROJECT DESIGN & FINDINGS

Housing styles vary throughout the country and so do the relative frequency and severity of different air conditioner and distribution system problems. The problems or savings opportunities encountered in SCE's service territory may be as or more important than those listed in Appendix A. A field investigation of high energy use houses in the Coachella Valley area of SCE's service territory was needed to characterize the local problems and opportunities.

Proctor Engineering Group designed a pilot project to identify the causes for high usage and fix them where feasible. The project was designed to target customers whose summer seasonal energy usage was in the top quartile for the area. A mailing was sent to customers informing them that they had been selected to participate in the pilot project and that the duct sealing and air conditioner modification services would be performed on their house if they met participation criteria and were one of the first 30 customers to reply. The marketing piece also summarized the services that would be provided and the potential savings associated with the repairs.

Based on prior PEG experience, the pilot focused on air conditioner problems and duct leakage as two potentially key factors in causing high usage. Shell leakage was also examined as a possible cause of high usage.

Two different program delivery approaches were tested. The first approach was to use local HVAC contractors and train them in duct system testing, diagnostics and repair. The second approach was to use a nationally known experienced duct retrofit contractor to perform the duct repairs. In all houses, the air conditioner testing and repair was performed by specially trained local HVAC contractors.

Implementation

PEG provided oversight and general management of the project. Two local contractors referred by a local distributor participated in the project. Conservation Services Group (CSG) was the duct retrofit contractor for the project. These contractors signed a contract with fixed costs of $375 per duct system and $240 per air conditioner. These costs were set with the assumption that the duct sealing visit would require a two person duct sealing crew fours hours (a total of eight person hours) to repair and seal the duct system and the air conditioner modification would require a three to four hour visit by the HVAC technician including refrigerant charge adjustment.

The sequence and duration of visits was a compromise between customer convenience and the necessities of effective time allocation. A number of alternatives were tried and a four visit method was the most viable. Included in these visits were:

1) House screening visit - Once the customer had responded to the marketing letter, each house was visited to access whether the house met the criteria for participation (combustion appliance safety and duct system accessibility). Many ducts were located in attic spaces with less than 24" clearance at the largest point.

2) Duct crew visit - A team of two specially trained technicians were allotted four hours (eight person hours) to complete the work on the house. The duct crew tested, repaired and re-tested the duct systems. They also tested for post-retrofit combustion appliance safety at each house.

3) HVAC technician visit - A specially trained HVAC technician tested the air conditioner and corrected deficiencies.

4) Inspection and customer satisfaction survey visit - Each house in the pilot was post-inspected and a customer satisfaction survey completed. These inspections verified that the repairs were correctly applied and the parameters reported by the project personnel truly reflected the final condition of the house and air conditioning systems. If problems were found the appropriate personnel were required to return and correct any deficiencies. In a production program only a portion of the houses would have an inspection visit.

The screening, duct, and HVAC personnel were trained to use step-by-step protocols developed by PEG. The screening training included one half day in the classroom followed by a half day in the field testing combustion systems and covering accessibility requirements. Daily review of the results and feedback continued for the duration of the project.

The duct crew personnel had one week of intensive training consisting of two days of classroom training on the fundamentals of duct systems and their interaction with the air conditioner and house, duct leakage testing and repair procedures, followed by three days in the field working as a group with a trainer. PEGís lead trainer worked directly with the duct sealing crews in the field throughout the duration of the project, supplying on-site management and feedback through daily form review of the jobs completed.

The HVAC technicians were given a one day classroom training on the fundamentals of refrigerant systems, followed by one day in the field as a group and one day of one on one training in the field with a trainer directly supervising their work. Daily form review and feedback was completed for all air conditioner modifications.

The work flow was house screening, duct and shell diagnostics and repair, air conditioner testing and repair, followed by a PEG inspection. Duct repairs were performed prior to air conditioner repairs because duct sealing affects the air flow rate of the air handler. The time required for each visit is shown in Table 2-1.

Table 2-1
Summary of Customer Visits

Visit	Time Required	Comments
Screening	Averaged less than 0.5 hours	Dependent on the number of combustion appliances
Duct Diagnostics and Repair	Averaged 4 hours (8 person hours) per system	Highly dependent on crew capabilities
HVAC Diagnostics and Repair	Ranged from 2 to 4 hours	Dependent on extent of AC problems
Inspection and Customer Survey	Ranged from 3 to 4 hours	All diagnostic tests were repeated. Inspection would be limited to a sample of units in production programs

One of the key aspects of project management was the daily form review and feedback on the work performed by project personnel. Since this was a relatively small pilot project, PEG was able to manually review all work on a daily basis. In a larger project this function must be performed with an automated (computerized expert) system. Contractors sent job site data to PEG daily via fax or in person. PEG's project managers reviewed the data nightly and provided feedback the following day. The data was entered into a data base, further analyzed for quality, and then calculations were performed to derive the system parameters of interest. The results of the inspection visits were also entered into the data base and the data was compared to the results reported by the contractors. Any significant variance between the inspection and reported data resulted in communication to the contractor to try to resolve the situation or, if warranted, a return visit by the contractor. The daily review and feedback process proved to be a valuable tool in aiding the contractors with the learning process and improving performance.

Pilot Project Testing and Data Collection Protocol

PEG designed the field testing and diagnostics to examine a wide variety of potential problem areas. The test procedures included many recently developed state-of-the-art diagnostic tests (particularly for assessing the duct systems). The key aspects of the field testing protocol are summarized in Table 2-2.

Table 2-2
Summary of Field Test Procedures

Parameter	Tests	Description / Use
Duct Leakage	Duct Blaster™ - exterior leakage	pressurize ducts to 25 pa with registers sealed, pressurize house to 25 pa using blower door (eliminating pressure difference between house and ducts), measure Duct Blaster™ fan flow, check pressures in other parts of duct system
	Half Nelson - return/supply leakage split	measure pressures in supply and return plenums with air handler on and registers sealed - results used to adjust Duct Blaster™ results into supply and return leakage rates
Air Handler Flow	Duct Blaster™ - pressure replication method	seal off return at furnace and use Duct Blaster™ as a powered flow hood to replicate supply system pressure (and flow) measured from normal air handler operation
	Flow Hood - direct air flow measurement	measure flow into all return grilles and sum for total air flow (only performed when return air grilles are directly mounted on a <u>sealed</u> platform plenum).
	Operating Static Pressures	measure static pressures in supply and return plenums - used in air handler flow tests, for estimating leakage under operating conditions, and for assessing duct design
AC Capacity	Enthalpy Change across AC coil	measure wet and dry bulb temperatures in supply and return plenums - combined with air handler flow rate calculate capacity under test conditions.
AC EER	Wattage Input	house electric meter measures electric input to AC, calculate EER (capacity/input) at test conditions.
AC Charge	Superheat / Subcooling	measure subcooling, superheat, head pressure, outdoor unit delta T, and power draw - compare to manufacturer target values when possible. Assess charge from available evidence including air handler flow rate, capacity, input, measured EER
AC other	Miscellaneous	collect nameplate information from indoor and outdoor units, assess potential outdoor unit air re-circulation
Duct Conduction	Duct System Location	estimate percentage of supply and return ducts in various locations (attic, garage, inside, etc.) - used to estimate ambient conditions around ducts for modeling conduction and leakage
Building Information	Building Shell Assessment	insulation R-values
Building Air tightness	Blower Door Test	measure CFM50 of house, also measure pressures developed in key building zones such as attics
Occupant Behavior	Interview Occupant	survey occupants about thermostat setting behavior (in detail), satisfaction with work, and perceived value

Findings - Targeting, Marketing and Screening

The final sample did not appear to represent the top quartile of summer seasonal use customers for the area. They appear to be representative of the general population. SCE provided submetered air conditioner data for a sample of customers believed to be representative of local air conditioned homes. When corrected for differences in weather the sample in the pilot study has very similar usage to the submetered group.

Southern California Edison mailed a marketing letter to customers in the Coachella Valley. Although the service was free to the first 30 respondents, response from the letter alone was not sufficient to fill the program. SCE performed outreach to customers that didn't respond to the mailing. In all, 105 customers agreed to participate. Eighty-six of these customers were visited for screening. Nineteen customers dropped out in the phone interview for a number of reasons: more than two air conditioners, insufficient access to the duct system, customer had lost interest, etc.

At the time of the screening visit two more houses were dropped because they had more than two air conditioners. Of the remaining houses, 26% passed all screening criteria in the first visit, 31% initially failed the combustion safety test, and 43% had inadequate access to ducts. Some of the homes that initially failed the combustion safety tests were repaired at owner expense and became part of the final 30 homes. Most of the homes with inadequate access to ducts had flat roofs with less than 24 inches of clearance. In some of the houses, access would have been possible if the customer had agreed to the addition of an access door, but they did not.

The access screen was the first applied, there were no combustion safety tests on homes what had inaccessible ducts.

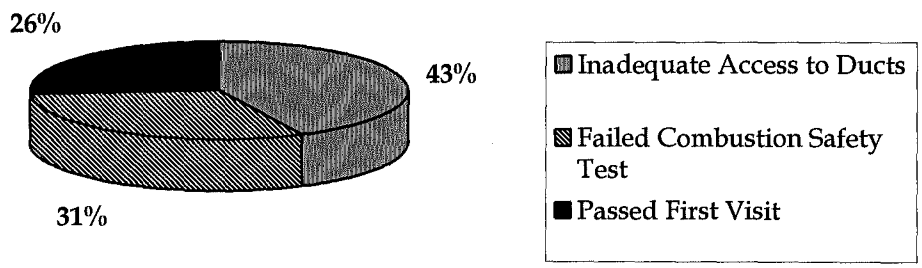

Figure 2-1
House Screening Results

Figure 2-1 demonstrates the importance of the screening visit. The phone contact had inquired about duct location, attic and other access criteria. Nevertheless, for this sample, only 26% of the homes could be worked on at the time of the first visit.

For the purpose of this study, combustion appliances in these homes had to meet the following criteria after five minutes of operation: CO in the flue less than 100 ppm, no spillage, and draft (measured as negative pressure in the vent with respect to the combustion appliance room) on a sliding scale dependent on outside temperature. Thirty one percent of the homes tested failed to meet those criteria. This is higher than the 25% failure rate noted in the PG&E Model Energy Communities project (Kinert, Engle, Proctor, and Pernick, 1992).

The breakdown for homes with combustion appliance problems is shown in Figure 2-2.

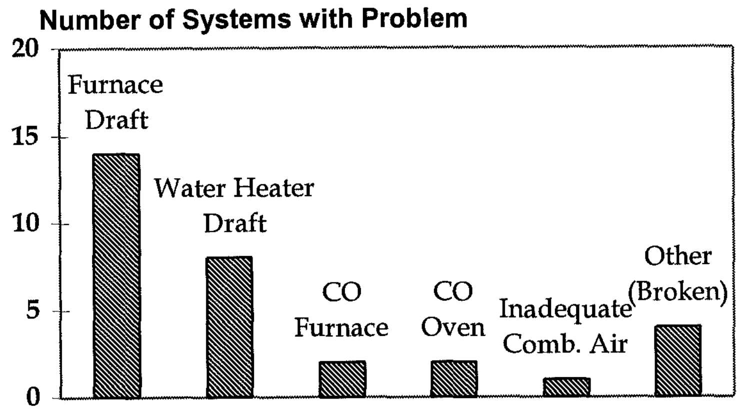

Figure 2-2
Occurrence of Combustion Appliance Problems

Five of the houses had multiple combustion appliance problems. The four houses with over 100ppm CO in the flue substantially exceeded that criterion. One furnace had over 2000 Parts Per Million (ppm) CO. Of the fourteen furnaces with inadequate draft, twelve had combustion product spillage. Five of the eight water heaters with inadequate draft also had spillage. None of the furnaces or water heaters with spillage were producing carbon monoxide above 100 ppm at the time of the tests. The most common cause of the inadequate draft was poor installation of the venting system or insufficient vent stack height. This project took place during the winter when the draft is the strongest (during the summer the hotter outdoor temperatures will lower the draft of the appliances making combustion product spillage more likely).

Other problems included a furnace cycling on the limit switch, a water heater that didn't operate and two inoperable furnaces. Each of the customers with combustion problems were notified of the seriousness of the problems and what repairs needed to be made for the system to operate properly. These customers were given the opportunity to have the problems corrected and to schedule another screening visit. Eight customers had the problems corrected and participated in the project.

Findings - General Characteristics

All of the houses were detached single family residences. This was not a stipulation of the screening criteria but all of the residences that passed both the accessibility and combustion safety screening were detached single family residences. The typical house in the pilot was slab-on-grade construction with stucco exterior, about 1962 square feet of living space. Roof systems were comprised of either flat roof construction or very low pitched gable roof systems. Most of the homes had R-19 in the attic (3 homes had R-11). Most supply ductwork was located in the attic. Most attics had very tight access, making the duct sealing work difficult and more time consuming than in previous projects performed by PEG. The air handlers were usually located in the garage or a utility closet. A number of return system designs were found: simple platform returns with a grille to inside, single round ducts beneath the slab floor, multiple return systems using interior wall cavities as chases. One common design was very prone to leakage and low air flow. That design used utility closet air handlers on a return platform. From the return platform a duct went up the wall, into the attic, then back down the opposite hallway wall to the return grille. This design was presumably to reduce noise.

The majority of houses in the project were older homes with large overhangs to shade the windows from the afternoon sun while the newer constructed housing had little or no overhangs for external shading. The lack of shading in the newer housing stock greatly increases the cooling load.

Findings - Building Shell Leakage and Achievable Reduction

All 30 houses were tested with a Minneapolis Model 3 blower door to determine the amount of leakage present in the shell of the house. Homes had an average blower door measured house air change rate of 10.2 ACH50 (Air Changes per Hour at a pressure difference of 50 pascals). Figure 2-3 shows the distribution of pre-retrofit house air change rates.

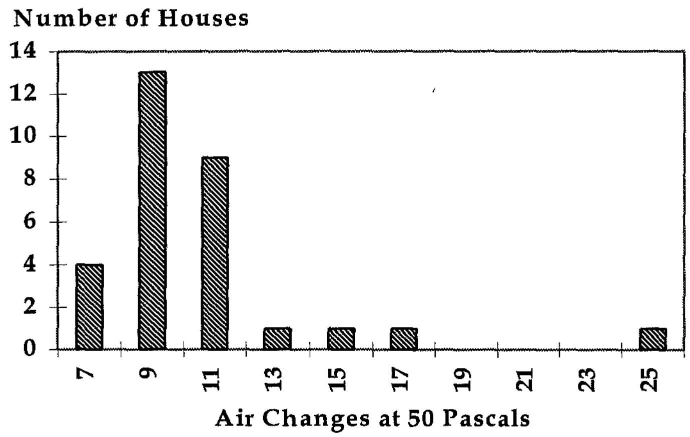

Figure 2-3
Building Shell Air Leakage Rate

Ventilation

ASHRAE Standard 62-1989 specifies the outdoor air requirements for ventilation in residential facilities in Table 2.3 of the standard (ASHRAE, 1989). That table includes the requirement that outdoor air be supplied to living areas at the rate of "0.35 air changes per hour but not less than 15 CFM per person". To evaluate whether these homes were likely to have an average natural ventilation rate that would comply with the standard, PEG applied a simplified version of the LBL infiltration model (Sherman, 1987). With this calculation an estimated minimum blower door leakage rate can be specified. This minimum leakage rate based on house volume is calculated as follows:

$$L_{Min} = 0.35 * V * N / 60 \quad (1)$$

Where:

L_{Min}	= Calculated Minimum CFM_{50} of the building
0.35	= ASHRAE standard (0.35 ACH)
V	= Volume of the house in cubic feet
N	= Divisor used to estimate natural ACH from CFM_{50} (based on the LBL model, ranged from 22.1 to 29.4)
60	= 60 minutes per hour

The average natural ACH estimated for the houses tested in the project prior to duct sealing was 0.42. After duct sealing the average was reduced to 0.38. The distribution of post-duct sealing estimated air exchange rates is shown in Figure 2-4.

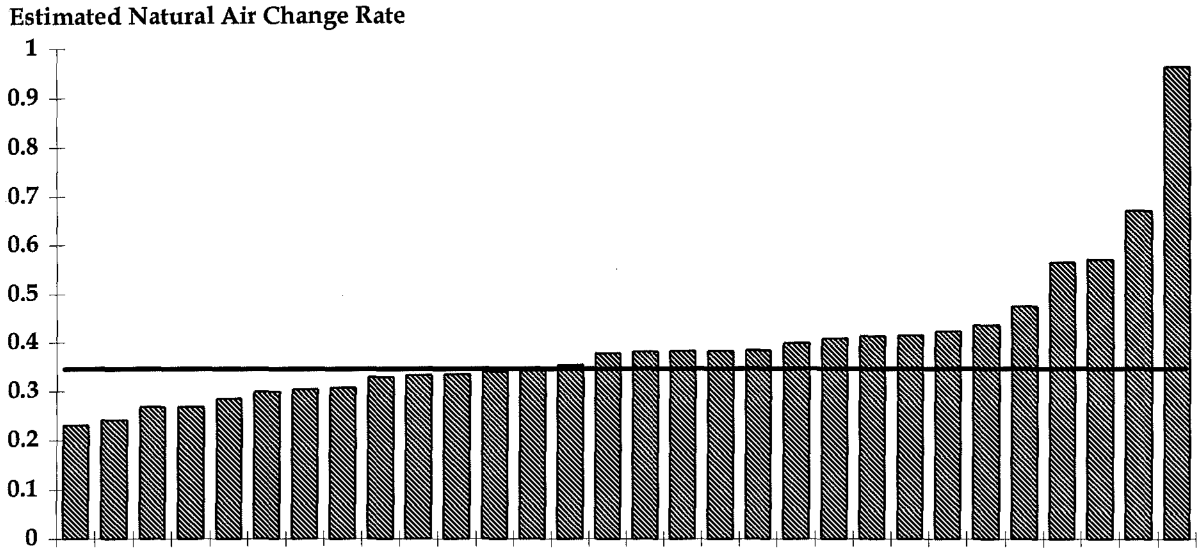

Figure 2-4
Estimated Post-Duct Sealing Natural Air Change Rate

Five houses with air exchange rates estimated to be below 0.30 ACH natural were retrofitted with exhaust ventilation systems. The ventilation systems fan size and solid state timer control was designed to supply the ventilation necessary to achieve an average estimated 0.35 ACH.

Four of the thirty homes had estimated air exchange rates that may make separate blower door guided building shell sealing cost effective. Another seven of the homes have shell air sealing opportunities that may be cost effective to address if the duct crews are trained (and have adequate time) to do effective attic to conditioned space sealing.

Figure 2-5 displays the shell leakage reduction available to bring the house to an estimated 0.35 ACH natural.

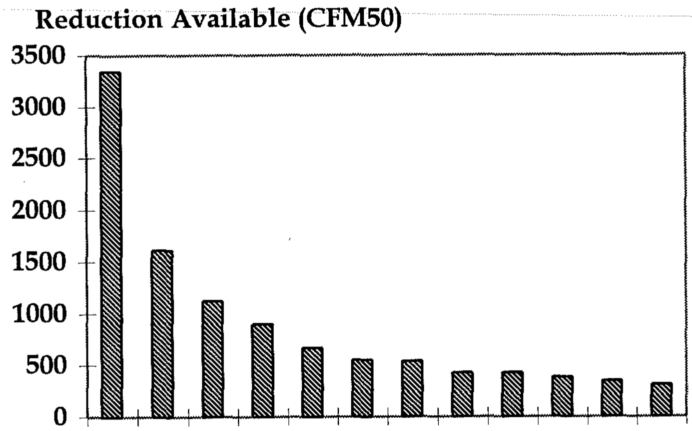

Figure 2-5
Available Shell Leakage Reduction

Findings - Duct Characteristics

The duct systems commonly consisted of 6" to 8" supply runs and 14" to 20" return runs of R-4 flex duct. Very few of the houses treated had rigid sheet metal duct systems. Those with rigid duct systems were in the older housing stock. Many systems were constructed with porous interior flex duct which provides an air barrier only on the exterior of the duct assembly, Instead of a plastic interior liner these duct systems have a mesh fabric, which is not air tight. This duct construction is designed to reduce sound transmission, but leads to extremely leaky duct systems as the outer vapor barrier on the duct becomes torn during installation or degrades over time. Some of these systems were impossible to repair, duct replacement was the only option.

Two common duct leakage problems were platform returns in utility closets (the most common) or garages, and wall cavity returns. Most of the platform returns were easy to repair with duct board and mastic. Wall cavity chases, however were often impossible to access and prevented leakage reductions in a large number of houses. One technique is to eliminate the wall chases, seal the platform and mount return grilles directly on the platform. This technique was very successful at eliminating return system leakage but can lead to customer complaints about noise and should be implemented with caution.

Findings - Duct Leakage

Duct leakage was measured to quantify the magnitude and impact of the existing leakage problems, and to measure the reduction in leakage from the retrofits. Duct leakage was also measured during most inspection visits to confirm the crews' reported numbers. Duct leakage can be measured in several different ways (see Proctor et al, 1993). Total leakage and leakage to the exterior at a particular test pressure are both directly measurable in most houses, but actual leakage flow rates to the exterior during normal system operation, split between supply and return, must be estimated to calculate the energy and peak effect of duct leakage.

In the pilot project, exterior duct leakage was measured using a Duct Blaster™ (a trademark of the Energy Conservatory) and a blower door. The test involves sealing all of the registers, then pressurizing the ducts to 25 pascals relative to the exterior while simultaneously pressurizing the living space to the same level using a blower door (in order to minimize any leakage between the ducts and the interior).

The average exterior leakage rate was 603 CFM50[1] before the retrofits, and 327 CFM50 after, yielding an average leakage reduction of 276 CFM50 (46%). The initial leakage rate is substantially higher than the 419 CFM50 measured in existing construction in Fresno, CA (Proctor 1991) or the 406 CFM50 measured by Tooley and Moyer (1989) in Florida. The distribution of exterior duct leakage rates before and after duct sealing is shown in Figure 2-6.

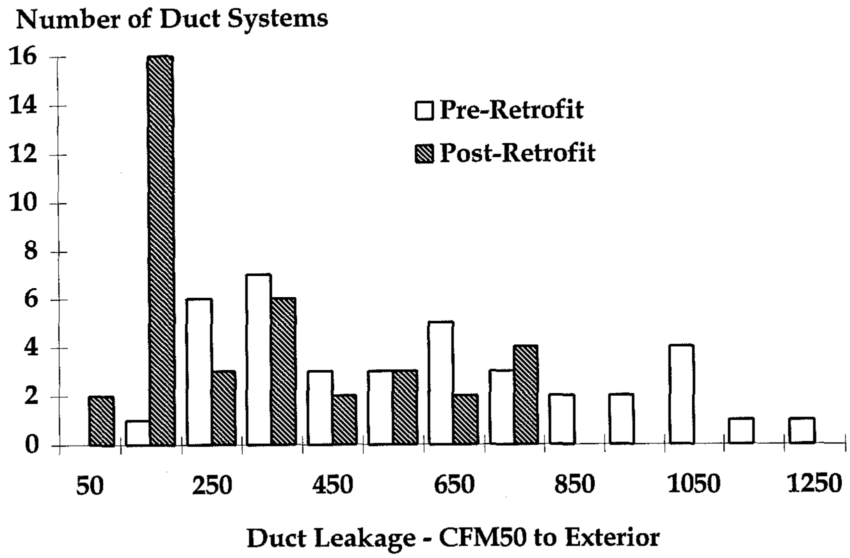

Figure 2-6
Duct Leakage to the Exterior

The pre-retrofit duct leakage rates varied widely from about 100 to 1300 CFM50. The leakiest system used pre-formed fiberglass ducts that had no interior or exterior air barrier. That system could not be fixed. The porous interior flex duct systems (found predominately in a development in Rancho Mirage) were also worse than average.

Exterior duct leakage averaged about 20% of total building leakage. This is higher than duct leakage rates found in most other studies of existing housing (for example 14.7% in Fresno, CA (Proctor, 1991) and 11.7% in Florida (Cummings et al., 1990).

The duct sealing crews were able to reduce leakage to less than 200 CFM50 on eighteen systems, a number of systems remained quite leaky after repairs. The 46% average leakage reduction is less than that seen in most retrofit projects previously completed by PEG. The main distinction between this program and the others was: the short duration of the project (the crews never reached the top of the learning curve), the proportion of systems with non-continuous air barriers, and the very difficult access to the duct systems. Inspectors found some cases where the crews did a poor job of fixing the systems, however in other cases replacing the duct system was the only possible solution.

The key quantities which impact energy usage are supply and return leakage under normal operating conditions (usually expressed as a percentage of the total system air flow). In this project, exterior leakage was allocated to supply and return based on the half Nelson test and the proportion of each side of the system within the conditioned space. The operating leakage for each side was estimated by adjusting the leakage rate to the average operating static pressure in that side of the duct system[2]. Finally, the

[1] Based on a flow exponent of 0.65.

[2] The flow exponent was assumed to be 0.65. The leakage at operating conditions therefore was calculated as Test Flow * (operating pressure/test pressure)^.65

operating leakage estimates were divided by the measured system air flow through the coil. The supply and return operating duct leakage rates are summarized in Figures 2-7 and 2-8.

The pre-retrofit leakage averaged 219 CFM supply and 253 CFM return, representing an average 18% and 24% of the air handler flow rates. The post retrofit leakage rates averaged 137 CFM supply and 132 CFM return (about 11% of the air handler flow rate on each side of the system). The return systems showed a larger reduction due to the extensive use of platform returns, which are relatively easy to seal. Supply systems were more difficult to seal due to both their size and their limited accessibility.

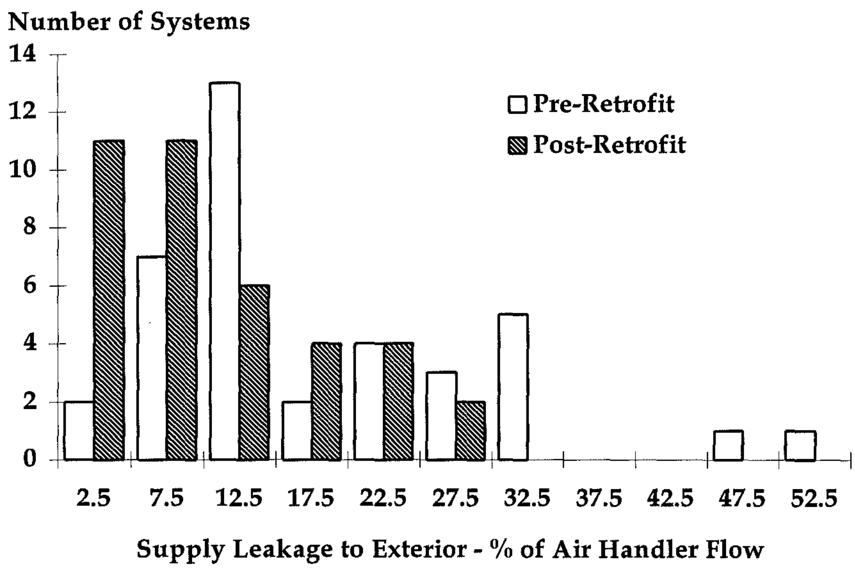

Figure 2-7
Supply Leakage to Exterior

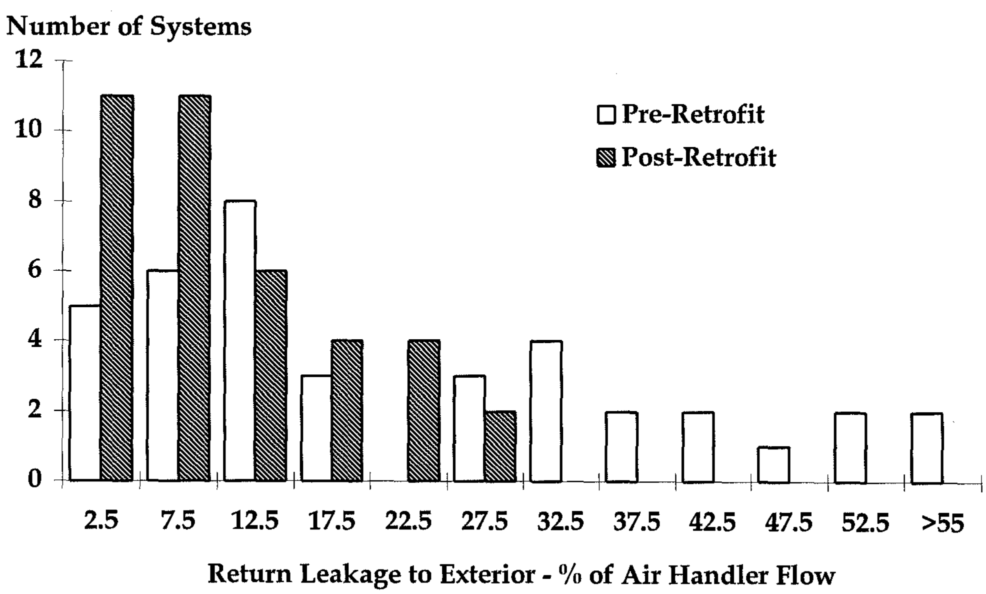

Figure 2-8
Return Leakage to Exterior

Findings - Air Conditioner Characteristics

Thirty seven air conditioners were tested in the pilot project (one customer moved prior to the air conditioner work). The houses had a wide variety of air conditioner makes and models. Rated Energy Efficiency Ratios (EER) ranged from 6.5 to 9.5 and averaged 7.7.[3] AC age ranged from new units, slightly over a year old, to units more than twenty years old.

General AC information for the sample units is summarized in Table 2-3.

Table 2-3
Summary of Air Conditioner Data

Parameter	Occurrence	Description / Notes
Customer Reported Heating Problems	24%	Mostly occurrences of recent repairs and lack of comfort in certain parts of the home.
Customer Reported Cooling Problems	35%	Mainly complaints of lack of cooling coupled with high bills and frequency of repairs.
Customer Reported System Age (years of age)	1-5 30% 6-10 39% 10-15 17% 15+ 14%	Air conditioner age ranged from 1.5 years to 20 +. Twelve different brands of air conditioners were included (GE and Day & Night were the most common). Most new air conditioners had old air handlers and coils in place. (Southern California Edison rebated outdoor units)
Customer Reported Frequency of Filter Replacement	3.7 Months	Frequency ranged from one to six months. Five customers reported not knowing where the filter was located or indicated that they never change it.
Customer Reported Service Visits Within Last 12 Months	55%	Average of 9 months since last service visit. Customers indicated that they usually have the system serviced only when there is a complete failure of the unit to operate (in either heating or cooling mode).
Outdoor Coil Cleanliness	Clean 35% Dirty 65%	Coils were examined and if dirty were cleaned prior to any refrigerant charge check.
Outdoor Coil Air Re-circulation	14%	These outdoor units had obstructions, such as overhangs, causing re-circulation of discharged air back into the unit.

Findings - Air Conditioner Systems

The air conditioning technician visit followed duct sealing (duct sealing affects air flow). Air conditioning technicians performed standardized testing procedures in the cooling mode for all air conditioners and heat pumps. These procedures determined the air flow rate, refrigerant charge condition, actual operating capacity, and instantaneous EER.

Of the 37 systems tested, only one system was operating with the correct air flow, charge, capacity and EER when first tested. All other air conditioners had at least one problem and many had numerous problems. Problems encountered were: low air handler flow and improper charge.

Air Handler Flow Rate

The proper operation of an air conditioning system depends upon the correct air flow across the indoor coil -- usually 400 CFM per ton of nominal capacity. In a hot/dry climate such as the Coachella Valley, where sensible cooling is almost the exclusive goal of air conditioning, higher air flow rates are

[3] For the 21 systems that the rated EER could be confirmed in the Carrier Blue Book.

recommended (higher air flow results in increased sensible capacity). Low air flow has been a common problem found in other studies of air conditioner performance (Proctor, 1991; Neal, 1990). In addition to potentially shortening equipment life, incorrect air flow renders most standard tests for proper refrigerant charge, such as superheat or subcooling, invalid.

System air flow rates were assessed using one of two techniques in the project. If the air handler was located on a platform return with grilles mounted on the platform and no other return runs, the air conditioning technician used a flow hood to measure the air flow (duct sealing crews had eliminated return leakage on grilled platform returns). On all other systems a PEG developed approach employing the Duct Blaster™ as a powered flow hood was used to measure flow. This procedure involves measuring normal operating static pressures in the supply system, sealing off the return system opening at the air handler and mounting the Duct Blaster™ so that it acts as the return. The air handler fan and the Duct Blaster™ fan are both run. The Duct Blaster™ fan speed is adjusted so the supply system static pressure equals the static pressure measured during normal system operation. When the pressures are equal, the flow through the Duct Blaster™ equals the air flow of the system. Figure 2-9 shows the distribution of measured flow rates before and after the air conditioner work.

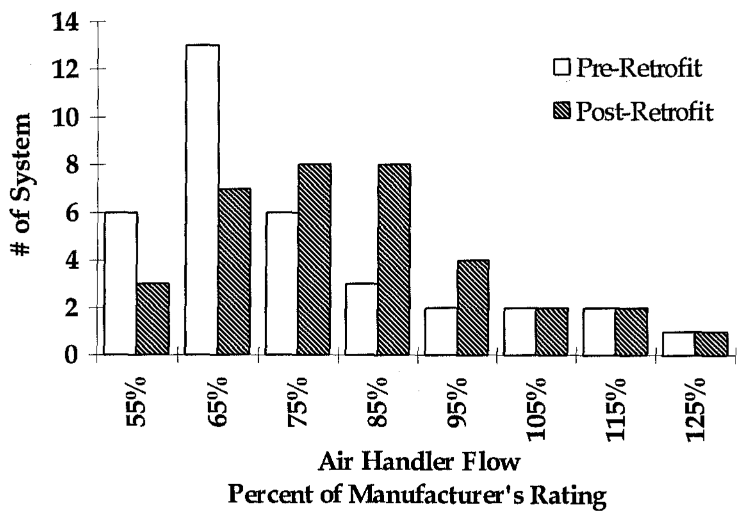

Figure 2-9
System Air Flow

Eighty percent of the systems examined had an initial air flow less than the recommended minimum (90%).

The pre-retrofit flow rates ranged from 200 to 490 CFM per ton and averaged 300 CFM per ton (25 percent below the target value of 400). Two thirds of the systems tested (23 of 35 units) had flow rates below 300 CFM per ton. Technicians were able to adjust flow on 18 of the 27 units with flow rates below 350 CFM per ton. These efforts had varying levels of effectiveness, producing an average increase in flow of only 42 CFM in those units. The average post-retrofit flow rate was 322 CFM per ton. Sixteen units still had flow rates below 300 CFM/ton.

There are numerous reasons for low air flow. The repair includes a number of steps:

- open registers and grilles
- replace dirty or clogged filters
- clean dirty or clogged indoor coil or air handler blower
- increase blower speed (used with caution, there is often an offsetting negative effect to this repair)

Table 2-4
Air Flow Correction Measures Applied
(Percent of Repaired Units)

Registers Opened	Filters Changed	Indoor Coil Cleaned	Air Handler Fan Cleaned	Air Handler Fan Speed Increased
74%	63%	48%	26%	15%

Almost half of the jobs had the indoor coil cleaned to increase the air flow. Some air handlers were located in tight access areas that would have required cutting of the refrigerant lines to gain access to the coil (the coil would need to be removed from the system and taken outside for cleaning). This was beyond the required level of effort for this program.

Air conditioners with low air flow that could not be brought to within the correct range were examined further to try to determine the cause of the low air flow. The Air Conditioner Contractors of America (ACCA) duct design manual (Manual D) suggests that the typical static pressure difference from before the fan to after the coil is 100 pascals (0.40 inches of water column). The systems with low air flow after repairs averaged 145 pascals (0.58 inches of water column). This average system pressure indicates that the duct system sizing and/or design is more restrictive than suggested and could be a cause of the low air flow. For other units, high external static pressure is not the cause of low air flow. Several of the air conditioners had low air flow <u>and</u> low static pressure (see Figure 2-10). These air conditioners were newer outdoor units with old air handlers. It is a common practice for contractors to replace the outdoor unit (sometimes with a larger unit) but not replace the air handler, indoor coil or modify the duct system.

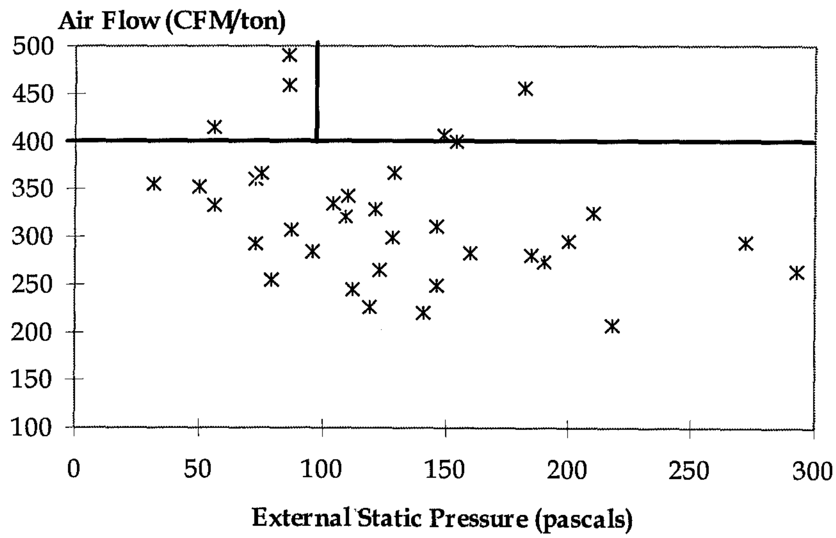

Figure 2-10
Post-Repair Air Flow and External Static Pressure

Only three of the systems were operating in the range of air flow and external static pressure preferred for this climate (the upper rectangle in Figure 2-10). Three items interact to cause this problem: oversized air conditioners, duct systems that are improperly designed for the flow they must carry, and undersized air handlers for the size of the outdoor unit. If the air conditioner is being replaced, a proper sized air conditioner (smaller) will probably be able to produce 400 CFM per ton with the existing duct work. If the air conditioner is not being replaced, an innovative option now being implemented by Conservation

Services Group is to upgrade the return system thus lowering static pressure, reducing duct leakage, and improving air flow. Due to the severity of the duct design and leakage problems in the Coachella Valley future retrofit projects will need to upgrade the duct system (sometimes including size) to increase air flow on some units.

Checking Refrigerant Charge

Manufacturers of residential air conditioning systems recommend various methodologies for determining proper system charge. Common to all manufacturers is the recommendation that systems have correct air flow prior to any attempt at assessing refrigerant charge. The repair techniques applied in this project did not succeed, for the most part, in bringing the air flow high enough to assess charge. The most common method of assessing charge for air conditioners with fixed metering devices (cap tube and orifice) is evaporator superheat. For systems with Thermostatic Expansion Valves (TXV) the subcooling method is suggested. Only two systems in this study had TXVs.

Evaporator superheat is the difference in temperature between the saturated refrigerant vapor in the evaporator and the refrigerant vapor in the suction line exiting the evaporator. The basic operation of a refrigerant system makes evaporator superheat a reliable method of checking refrigerant system charge under many conditions. In order for this method to be accurate several items must be determined prior to its use:

- Air flow through the indoor coil must be within +/- 50 CFM of the manufacturers suggested flow (400 CFM per ton).
- Refrigerant system evacuation must be complete (all non-condensables must be removed from the system).
- The indoor and outdoor temperatures must be within the range specified by the manufacturer as being acceptable for checking charge though the superheat method.

There is one major drawback to using the superheat methodology in hot dry climates such as Coachella Valley. The superheat methodology is useful for conditions that exist in the more humid and cooler parts of the United States. It will not work in hot dry climates that experience low indoor wet bulb temperatures in combination with high outdoor dry bulb temperatures.
This can be illustrated by the superheat charging chart shown in Figure 2-11. The superheat charging method consists of running the air conditioner long enough to reach steady state, then testing the superheat, indoor wet bulb temperature and outdoor dry bulb temperature.

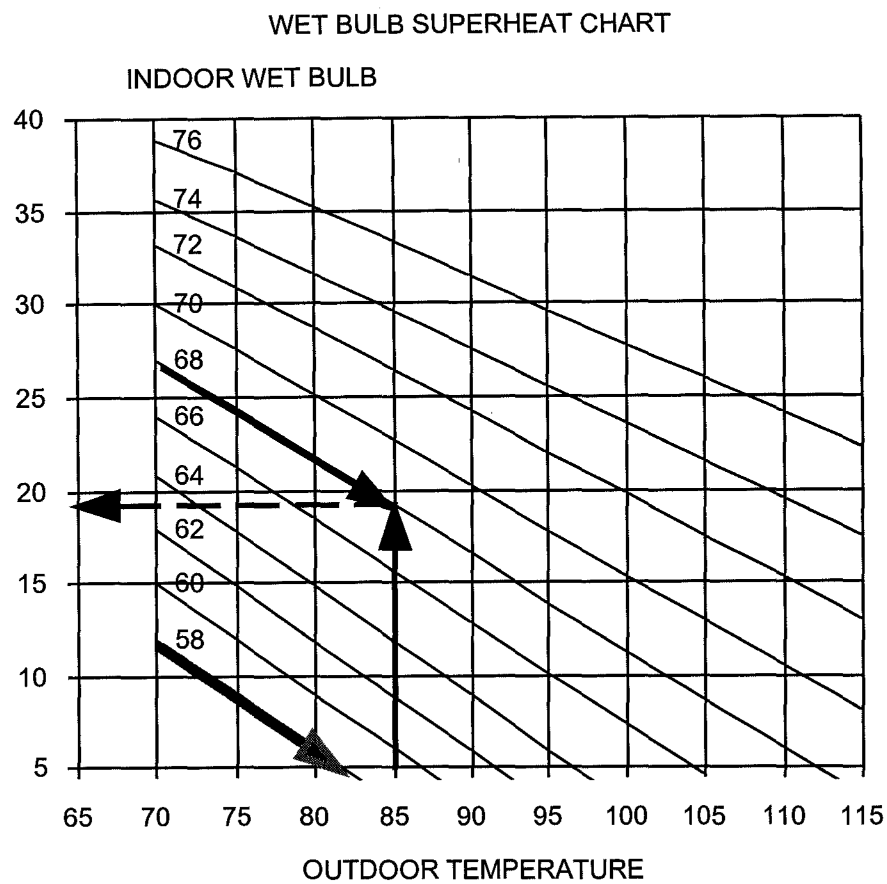

Figure 2-11
Superheat Charging Chart

For a given indoor wet bulb temperature and a given outdoor temperature the target superheat can be read off the chart. For example if the indoor wet bulb temperature is 68°F and the outdoor temperature is 85°F the target superheat can be determined by following the diagonal line marked 68°F to the vertical line marked 85°F. Moving straight to the left from that intersection point the target superheat can be read as 19°F.

However, for an indoor dry bulb temperature of 75°F the indoor wet bulb in Coachella Valley region is often below 58°F. (In our tests the indoor wet bulb averaged 55°F with a dry bulb of 68°F). If the 58°F (the lowest diagonal line) on Figure 2-11 is followed to the lower limit of the graph it is apparent that the outside temperature cannot exceed 82°F to check charge in this manner. An outdoor temperature of less than 82°F during daylight hours in the cooling season is rare in the Coachella Valley region (the average outdoor temperature during our testing was 78°F and the testing was completed during the months of February and March).

There are at least two approaches to the problem of ensuring correct charge in hot/dry climates. The first is to ensure that the service technicians have the proper equipment (and training to use it) to properly evacuate and weigh in the correct amount of charge. The second approach is to work with manufacturers and researchers to devise a charge test that is easily applied in hot/dry climates.

An advantage to the second option is that the optimal charge could be determined for these hot/dry climates (the optimal charge for a hot dry climate is not necessarily the same as the optimal charge for the purpose of an SEER rating based on 82°F outdoors). Research at Texas A&M University has shown for higher temperatures that air conditioner capacity is greater and efficiency is higher for systems containing less than the manufacturers specified charge (Farzad & O'Neal, 1988). This is illustrated in Figure 2-12.

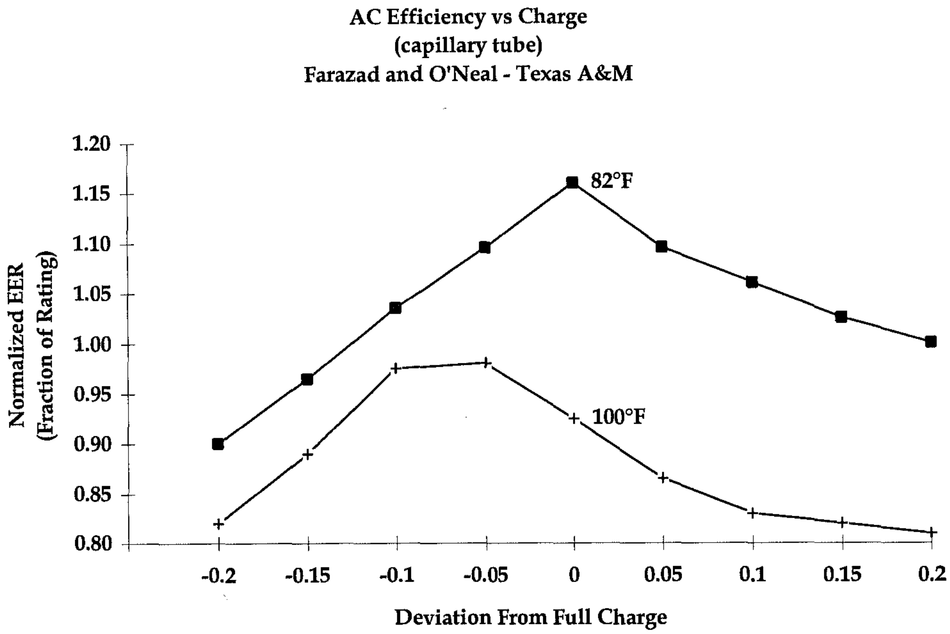

Figure 2-12
EER vs. Charge and Outdoor Temperature (capillary tube system)

Refrigerant Charge

Incorrect refrigerant charge is a common problem with air conditioning systems. Prior to being able to check for correct refrigerant charge, it must be established that the air flow through the indoor coil is correct. The systems with correct air flow examined in this pilot had their superheat or subcooling checked to determine if the charge was correct. This approach is usually effective at determining whether a unit is properly charged. However, some of the systems with correct air flow could not be checked due to the low indoor wet bulb temperatures. A total of ten systems (or 27%) were able to be brought within the correct air flow range. Of these units, 9 were able to be correctly assessed for refrigerant charge. The results of are summarized in Table 2-5.

Table 2-5
Air Conditioner Refrigerant Charge

Charge Indication (n = 9)	% of units
Correct	11%
Undercharged	56%
Overcharged	33%

This retrofit project was one of the first of its kind to examine charge in a hot dry climate such as the Coachella Valley. While the majority of the systems could not be brought within the correct air flow range, the ones that could be for the most part could not be assessed for correct charge due to the problems outlined previously. Previous studies by PEG have found a range of 21% to 41% undercharge and 27% to 36% overcharge in existing air conditioners (Proctor and Pernick, 1992).

Air Conditioner Sizing

While estimating the cooling load was not part of this project, it was apparent to the investigators that most homes had substantially oversized air conditioning systems. High static pressures resulted from the relative sizing of the air conditioner to the duct system.

Palm Springs is a very hot climate, but there is virtually no latent load. Older houses in the project, which was the majority of the houses, were climate sensitive designs with large overhangs shading the windows from the afternoon sun. Unfortunately this design has been abandoned in the newer constructed housing which have small or no overhangs for external shading. The lack of shading in the newer housing stock greatly increases the cooling load as compared to the older housing.

Findings - Customer Satisfaction and Willingness to Pay

Thirty of the customers were interviewed at the time of the inspection. Due to the season (early spring) and the short time between the work and the inspection, most of the customers had not used their air conditioners since the retrofit. Ninety five percent of the respondents rated their overall satisfaction as Good or Excellent. All of the respondents rated the crew and AC technicians performance as good to excellent. One respondent was not happy with the increased noise that resulted from removing the leaky and restrictive return system and replacing it with direct grilles into the return platform. The return duct system was later returned to its original configuration.

Forty nine percent of the respondents said that they would be willing to pay for the service. Only four customers were willing to estimate the amount that they would be willing to pay. Their estimates ranged from $200 to $400.

Survey results are summarized in Table 2-6.

Table 2-6
Customer Satisfaction and Willingness to Pay

Item	Response
Overall Satisfaction (n=19)	95% Good to Excellent
Duct Crew Performance (n=21)	100% Good to Excellent
AC Technician Performance (n=20)	100% Good to Excellent
Willingness to Pay (n=19)	47% Yes

Summary of Field Findings

The homes in this sample have tight building shells and duct systems that are nearly 50% leakier than duct systems measured in other studies. Many of the homes are estimated to have less than 0.35 ACH for ventilation when the windows are closed. Table 2-7 summarizes key system parameters measured in the pilot project.

Table 2-7
Summary of Field Findings

				Leakage Fractions								
	Duct Leakage CFM50			Supply %		Return %		Air Flow/ton		Rated Cap.	Floor Area[4]	Shell Lkg.
	Pre	Post	Dif	Pre	Post	Pre	Post	Pre	Post	Btuh	Sq. Ft.	Pre
Mean	603	327	276	18.2	10.9	23.9	11.5	300	322	47959	1962	3035
Std.Dev.	300	224	187	11.8	7.2	20.6	12.6	73	68	10385	645	1760
Median	558	239	210	12.8	8.6	15.0	5.7	279	307	48000	1873	2700

[4] Eight houses had two air conditioners, the floor area and shell leakage statistics are for the houses, all other statistics are for the air conditioner systems.

3

DELIVERY MECHANISMS

One of the goals of the pilot project was to compare two alternative delivery mechanisms for the duct sealing work. While all contractors were given the same amount of training and all received feedback on their work in a timely fashion, not all were able to achieve the same results. Figure 3-1 summarizes the results of the duct sealing work by contractor.

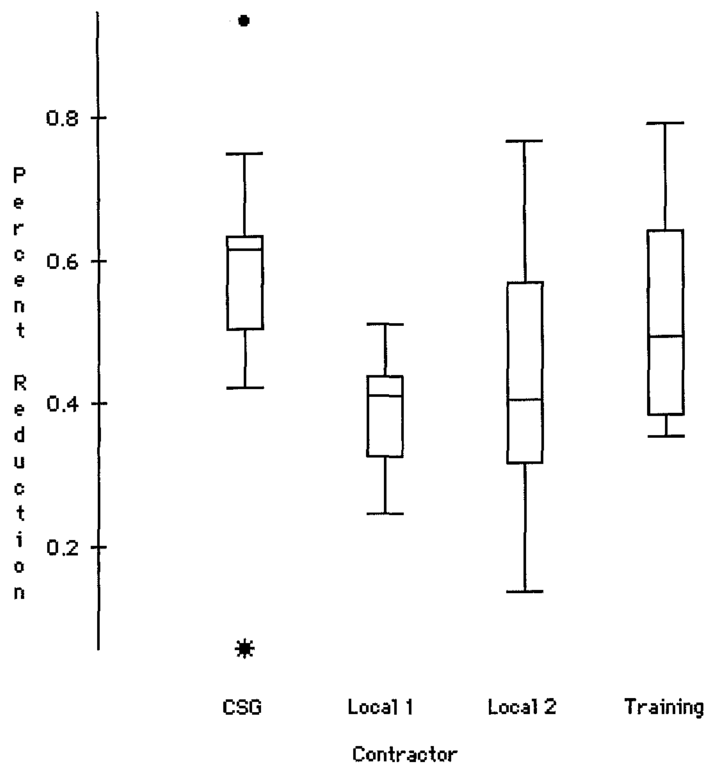

Figure 3-1
Contractor Effectiveness

Conservation Services Group performed better than either of the local contractors. The duct sealing jobs were assigned on a random basis by SCE's administrative office in Cathedral City to ensure that there was no bias in distribution of the jobs.

CSG used an experienced duct technician and one new technician who was trained during the pilot. They traditionally focus on this type of work and were able to perform well on homes that had duct systems that could be sealed

Local Contractor #1 used their normal duct installation crew. That crew had a difficult time comprehending the testing procedures, the prioritization of work, and how to implement corrective repairs. This crew received a great amount of individual training including: daily visits from a PEG staff person to check on their progress, assistance with problems, and direction of their efforts. Nevertheless, this crew did not comprehend the testing procedures by at the end of the project. Their work tended to be misdirected (sealing low priority but easy access areas first) and of low quality. Many of their repairs had to be redone. Because of the additional time that it took them to complete jobs (some requiring more than a full day) they completed only seven systems.

Local Contractor #2 used top level AC service technicians to perform the work. These technicians would not normally be expected to continue as part of a duct sealing crew, but they showed a good learning curve and were capable of performing well.

The air conditioning technicians from both contractors performed at similar levels of competency. The technicians performed quality work which resulted in very few return trips once they had become clear on the standards of the project.

Air Conditioning Contractor Infrastructure

It is a common expectation among the general public that after an air conditioning contractor has serviced a unit that it will be properly charged and operating at the capacity and efficiency that they were designed to deliver. Unfortunately, as seen in this study, the air conditioners are rarely performing as they should. In addition to the problems associated with checking charge in the hot/dry climate of the Coachella Valley, technicians often rely on rules of thumb and guesswork. Many technicians consider testing air flow and charge parameters such as superheat or subcooling unnecessary and too time consuming

While the primary responsibility for this shortcoming lies with the contracting industry and the technicians themselves, a portion of the responsibility also lies with the customer. The majority of customers would not be willing to pay for the additional labor required to correctly service a unit when they can get another contractor who says they can deliver the same service (an air conditioner that delivers cold air) for a much reduced cost. One of the main obstacles to getting quality work is customer ignorance of what constitutes good service and customer reluctance to pay for quality service. The air conditioning service industry, like any other is market driven, responding to customers' willingness to pay. A downward spiral of quality has been established that leads to poorly operating systems, shortened equipment life, customer dissatisfaction, high bills for the customer and high demand for the utility.

PEG has been active in developing step-by-step approaches for assessing air conditioner performance based on a combination of measurable system parameters. This study confirms that given a comprehensive procedure to guide technicians through the assessment, technicians most systems can operate at the correct capacity and efficiency. The contracting industry, manufacturers, and utilities need to work together to correct the present infrastructure shortcomings.

4

MODELING IMPACTS ON USAGE & PEAK DEMAND

Predicting the impacts of the duct and air conditioner retrofits on energy usage and peak demand requires an analysis which models the air conditioner, duct system, and building shell and incorporates the interactions between them. For example, when a leaky return draws air from the attic it raises the temperature at the inlet to the indoor coil resulting in an increase in air conditioner capacity and watt draw. PEG has adapted the Palmiter Duct Model (Palmiter and Bond, 1991) and created an AC model for dry climate performance. These models are combined into a comprehensive model that incorporates many of the complex interactions in the systems studied. The model calculates system efficiencies, losses, loads, energy usage, and demand at a series of outdoor temperature bins based on a typical weather year in Palm Springs.

A realistic analysis of peak demand impact also requires characterizing the effect of occupant behavior patterns on actual cooling demand. PEG has developed a model which utilizes submetered air conditioner data to characterize the interactions between occupant behavior patterns/cooling load and effective capacity. This peak model (Model P) significantly improves upon most existing peak models which usually employ a single general residential AC demand curve.

Air Conditioner Performance Modeling

Air conditioner performance can be characterized at given conditions by system capacity and EER. These two quantities can be used to calculate the power draw and, along with air handler flow rate, the temperature drop across the indoor coil. System capacity is modeled as a function of outdoor temperature, return plenum temperature, air handler flow rate, and charge. The model assumes a nearly dry coil given local climate. EER is modeled as a function of outdoor temperature, return plenum temperature and charge. The air conditioner model return plenum temperature is calculated from the duct system model.

For both capacity and EER, each factor effecting performance is represented as a multiplicative adjustment to the rated value. The adjustment factors are based on available published data and studies by PEG. This model is discussed in Appendices B and C.

Duct Efficiency Modeling

The impacts of duct leakage and conduction on effective system efficiency and building loads are complex. Duct leakage can cause four types of efficiency losses:

- the supply air that leaks to the exterior is a direct efficiency loss;
- the return air coming from outside and spaces warmer than outside (e.g. the attic) adds to building loads;
- the supply and return flows increase the air leakage rate of the building shell depending upon the relative size of the flows and the building's natural infiltration rate;
- when the air handler is off, the duct leaks still add to the building shell leakage rate.

Each of these effects is accounted for in the duct efficiency model. The duct leakage model inputs include the supply and return leak fractions (as a percentage of the air handler flow rate), the temperature of the air surrounding the return ducts, and the natural air leakage rate of the building shell (based on the blower door test and a limited implementation of the LBL infiltration model).

Conductive heat gain into the ducts is modeled as a function of duct area, R-values, the temperature of the air around the ducts (which depends on outdoor temperature and duct location), and the temperature of the air in the ducts (which depends on the air conditioner capacity, duct air flow, and duct leakage rate). Conductive heat gain to the ducts is assumed to occur simultaneously with system operation (i.e., no losses during off-cycle, full load losses during entire operating time). This approach makes efficiency losses due to duct conduction dependent on the capacity of the air conditioner and as such are dependent on the relationship between the load, capacity, and duct size.

The leakage and conduction models interact in terms of calculating return plenum and average supply duct temperatures and in avoiding any "double-counting" (e.g., the efficiency loss due to conductive gains into the portion of supply air which leaks out of the ducts is not included).

Energy Usage Modeling

All of the duct-related losses are expressed in terms of percentage efficiency losses to the air conditioning system. The effective capacity of the air conditioner is calculated as the system capacity at given conditions adjusted for duct efficiency losses. These calculations are performed at each of eight temperature bins (see Table 4-1) for summer conditions in Palm Springs.

Table 4-1
Palm Springs Summer Temperature Bins

Bin Temperature	Hours
<80	2171
82.5	674
87.5	583
92.5	554
97.5	513
102.5	391
107.5	179
112.5	71
116	1

The model calculates the cooling load of the building shell as a function of the estimated design load. The design load is separated into four components: solar gain, conductive gain, infiltration, and internal gains. The load for a given temperature bin is then calculated as a function of outdoor temperature (including a linear component for conduction and non-linear component for infiltration), average sunshine at that temperature, and constant internal gains. Design load data were not collected and analyzed during this project (due to budget constraints), so model sensitivity to design loads were tested at various levels. Based on available end-use metered data from other customers, the primary conclusions of this study are based on a design load of 35.7% of rated capacity.

The model uses the effective capacity and the building shell load to calculate the duty cycle, which is used to calculate the hourly energy usage (adjusted for cycling losses). These calculations are performed at each outdoor temperature bin. The analysis for each bin is performed assuming that each unit is controlled by a constant thermostat setting (78.9°F based on the average result from occupant interviews). To account for occupants not using their air conditioner (not at home or otherwise off by choice) the model multiplies the predicted usage for each bin by the probability that an air conditioner is "on" at that temperature. The probabilities used in the model are based on PEG data and a published study based on California households (Harlan and Svheer, 1985). The annual energy usage rate is estimated as the sum of the bin consumption weighted by hours in that temperature bin.

Peak Demand Modeling (Model P)

The diversified demand of air conditioning systems during system peak involves more than simply modeling performance and efficiency during peak conditions. Occupant behavior patterns can have a large influence on actual demand during peak. Some households (referred to as Group A) have no air conditioning use during peak. These homes may be unoccupied at that time or the occupants have the air conditioner switched off. Other households may have the air conditioner running continuously (Group D), often because the occupants have recently adjusted the thermostat down. Another group of households (Group B) have their air conditioners cycling on and off based on thermostatic control. Some households may have a constant thermostat setting in the period of interest but the effective capacity of their air conditioning system is less than the load. These households (Group C) have air conditioners running continuously, but some achievable reduction in load or increase in effective capacity would result in them cycling. The proportion of households in each of these categories must be estimated to arrive at reasonable estimates of diversified peak demand.

PEG received a sample of load research data from SCE in order to estimate the proportion of households in each of the above customer groups during system and residential peak times (system peak is at 3-4 PM on hot weekdays, residential peak is 5-6 PM on the same days). The load data is from a random sample of twenty existing Palm Springs residential customers. The data set is from the summer of 1994 and includes five very hot days which are typical of system peak conditions (outdoor temperatures reaching 113°F-116°F). PEG analyzed this data and classified each customer-peak hour into one of the four groups. The percentage of customers in each class is shown in Figure 4-1.

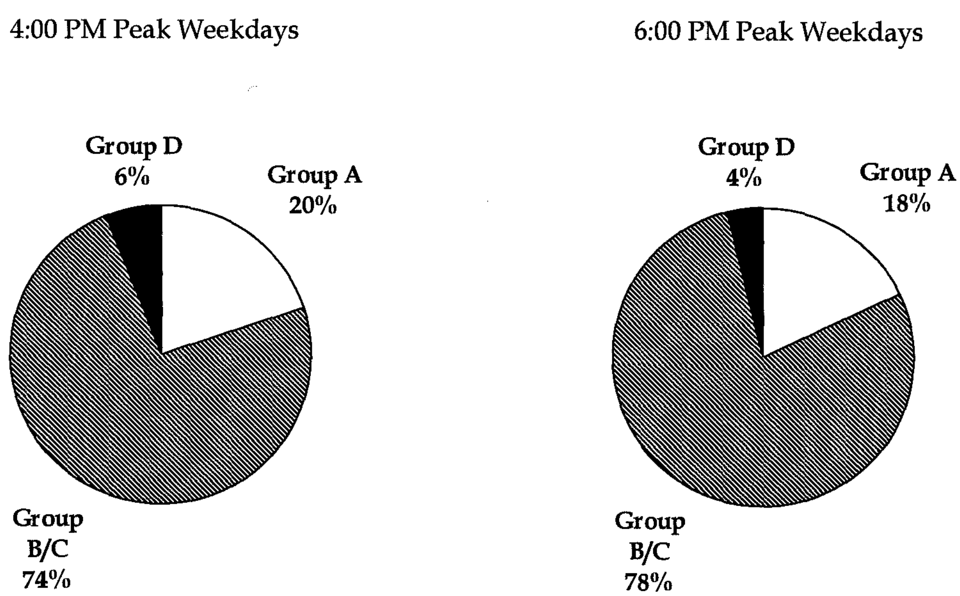

Figure 4-1
Model P Classes from Submetered Sample

The diversified demand is calculated as the weighted sum of the demands of the four Model P classes. Group A households have no demand at peak. Group D households' demand equals their connected load. Group B and C households are in a constant thermostat setting mode and their duty cycle changes as different scenarios are modeled. This approach is discussed further in Appendix B.

Summary of Model Inputs

The cooling model requires information on numerous aspects of the air conditioner, the duct system and its surroundings, and the building shell. Table 4-2 describes the inputs and the sources used in this project.

Table 4-2
Model Inputs & Data Sources

Category	Model Input	Source / Assumption
Temperatures	Outdoor Temperature	Bin data for Palm Springs, peak of 116°F
	Indoor Temperature	78.9°F based on survey average
	Temperature surrounding ducts	location weighted average of outdoor and attic temperatures (assumed 20°F higher than outdoor when in full sun)
	Temperature of infiltrating air	assumed 50% at attic temperature, 50% at exterior temperature
Duct System	Supply & return leakage fractions	based on Duct Blaster™ tests, air flow test, and operating pressure measurements
	Duct Area (square feet.)	based on # of runs, sizes
	Duct R-Value	R-4 based on insulation thickness
Air Conditioner	Rated capacity & EER	from nameplate information and published values
	Air Handler Flow	from field tests using Duct Blaster™ as powered flow hood
	Charge	from field tests where conclusive, otherwise assumed at proper charge
Building Shell	Cooling load	Design load estimated as 36% of installed capacity (based on PEG data), design load adjusted to temp. differential. and percent sunshine based on estimated load components of solar, conduction, infiltration, and internal gains
	Air tightness (CFM50)	from blower door test

Modeling Results

When applied to the data from the 38 systems in the pilot project, the comprehensive model estimates the distribution system losses shown in Table 4-3

Table 4-3
Estimated Pre-Retrofit Distribution Losses

	Average	Peak
Total Distribution Loss	49%	62%
Leakage Loss	35%	44%
Conduction Loss	14%	18%

For the air conditioners retrofitted in this project, the energy and demand models predict the cooling consumption and diversified peak shown in Table 4-4.

Table 4-4
Estimated Energy Consumption, Peak Load, and Savings

Condition	kWh	kW at 4 PM	kW at 6 PM
Pre-Retrofit	4739	4.99	5.10
Post-Retrofit	4018	4.66	4.75
Savings	721	.33	.35
Percent Savings	15.2%	6.6%	6.9%

These results varied by contractor as shown in Table 4-5.

Table 4-5
Estimated Energy Savings by Contractor

Contractor	kWh
CSG	22%
Local 1	8%
Local 2	16%

The 22% projected savings is similar to the submetered 24% savings achieved on duct and AC repairs on the top quartile of AC users in Fresno, California (Proctor and Pernick, 1992). Using the initial sizing projections the model indicates that about half of the air conditioners are unable to meet building loads at 112°F and a quarter of the units can't meet loads at 102°F before retrofits. Therefore, some of the efficiency gains from the retrofits are realized as improved comfort (i.e., more air conditioners are now capable of cooling the house to the setpoint). There is a projected increase in effective cooling capacity at peak of 47% due to these repairs.

Actual building loads are unknown so the sensitivity of the model results to alternative load assumptions was tested. The baseline model assumed that the house cooling load at design conditions was 35.7% of the rated capacity of the installed air conditioner. The model was rerun with house cooling loads ranging from 16.7% to 50% of installed rated capacity. The average kWh savings varied very little over this wide range (508 to 769 kWh). These results are shown in Appendix C.

The baseline model was checked against billing data from these houses. The average cooling energy usage estimated from billing data was within 5% of the average predicted energy consumption. On a house by house basis the correlation between the billing derived and model derived usage estimates was poor (this was expected given the large impact that behavioral variations have on cooling usage).

Notes on the Comprehensive Model

The comprehensive model used in this study is unique in modeling many of the interactions between the ducts, air conditioner, and building shell. At the same time it, like all models, is based on simplifications of the systems involved. Additional research is needed on air conditioner performance in hot/dry climates under peak conditions, particularly with typical field conditions (other than "correct" charge and air flow).

Actual cooling loads are highly subject to customer interactions and only metered data can accurately determine the relationship between cooling demand and capacity. The amount of peak reduction attainable through retrofit duct sealing and air conditioner repairs is highly dependent on the actual cooling loads. The original timeline and budget for this project did not allow for submetering of these homes. An analysis of hourly sub-metered usage patterns from homes with known construction characteristics (all the information necessary to estimate design cooling load) and installed capacity could be used to "true-up" these estimates to typical relationships between design load and capacity. Proctor

Engineering Group recommends that projected savings and peak reductions be verified by metering a sample of buildings. The projected energy savings should be verified by a billing analysis of the homes in the pilot.

5

CONCLUSIONS AND RECOMMENDATIONS

Existing homes in the Palm Springs region of Southern California Edison's service territory have substantial deficiencies in their cooling systems. The duct leakage problems in these homes exceed those found in studies from other parts of the country and other parts of California (44% leakier than existing systems in Fresno, California). Air conditioner problems are similar to those found in other studies (only one of the systems had the proper air flow, refrigerant charge, operating capacity and EER when first tested). These homes fall roughly into two categories, homes where effective repairs can be made at moderate cost, and homes where ducts are difficult to access and repair costs will be high.

In homes where repairs were made, the modeling results show reduced energy usage and demand with improvements in occupant comfort.

For relatively inaccessible ducts new methods of duct repair need to be developed.

Conclusions

- Houses must be visited and screened for combustion safety or accessibility problems that preclude inclusion in the program. Thirty one percent of the homes failed the combustion safety tests and forty three percent of the homes had insufficiently accessible ducts.
- Duct leakage and existing duct insulation levels cause an average loss of 49% in overall cooling efficiency.
- Existing duct systems in pilot homes have an average efficiency loss at peak of 62%.
- The effectiveness in sealing ducts was dependent on the contractor used.
- In homes that have accessible duct work the modeled cooling energy savings from the repairs in this pilot averaged 22% using the most effective contractor. The average cost of these repairs was $615 ($375 for ducts and $240 for AC repairs).
- Using the most effective contractor the modeled diversified peak reduction under baseline assumptions is 0.46kW at system peak and 0.49 at residential peak.
- With the most effective contractor, the effective capacity (cooling capacity actually delivered to the house) of the air conditioners was increased by an average of 60% under peak conditions.
- Customers were highly satisfied with the program (95% rated the program as good or excellent) and 45% indicated a willingness to pay for the service.

Southern California Edison has a potentially worthwhile option for improving cooling efficiency, reducing peak demand, and increasing customer comfort. Proper program design, contractor selection, training, and quality assurance are critical issues for actually achieving these improvements.

Recommendations

1. Program implementation should begin with a number of submetered houses (comparison and experimental) to verify the model results and to determine the achievable level of capacity reduction.

2. The program should use highly trained duct repair crews that can screen air conditioners for problems. This change should reduce the overall cost of the program.

3. Where peak electrical consumption is a primary concern, early replacement of existing air conditioners with high efficiency units[5] of proper size should be considered. When this approach is combined with duct system repairs substantial peak reduction can be achieved with equal or improved customer comfort.

4. The following additional research is recommended:

    - Air conditioners on a sample of existing homes with known construction and air conditioner capacity in the Palm Springs area should be submetered. This can be combined with the first recommendation.

    - Air conditioner performance should be laboratory tested under a wide variety of operating conditions (air flow, charge, indoor temperature, and outdoor temperature) and system types. This would assist in modeling the air conditioner under peak conditions "typical" to Palm Springs.

    - The aerosol duct sealing methodology being developed by Mark Modera of Lawrence Berkeley Laboratory should be tested on a number of Palm Springs homes with relatively inaccessible duct work. This new technology holds promise for cost effective results.

[5] "High efficiency" here should not be construed as high SEER. High efficiency at peak conditions is of primary importance and SEER is not a reliable indicator of efficiency at peak (Proctor et Al. 1994).

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GLOSSARY

97.5% Design - ASHRAE published values for outdoor design temperature that will be exceeded on average 73 hours of the summer months (June through September).

ACCA Manual J - Residential heating and cooling load estimation methodology published by the Air Conditioning Contractors of America.

Air Changes per Hour (ACH) - The number of times that air in the house is replaced with outdoor air in one hour.

Air Handler - The fan and cabinet assembly that moves air across a heat exchanger and through a duct system.

Blower Door - A large variable speed fan fitted with flow and pressure measuring devices. It is mounted in a doorway to measure the leakage of a structure.

Capacity - The amount of heat added to (heating) or removed from (cooling) a structure by the heating or cooling equipment.

Capillary Tube - A refrigerant metering device that utilizes fixed diameter and length of tubing to control the flow of refrigerant.

CFM50 - A measurement of the house air leakage based on the air flow necessary to maintain a 50 pascal pressure differential between the house and outside.

Charge - The quantity of refrigerant in a system.

Connected Load - The amount of power draw when the unit is running continuously.

Design Cooling Load - The heat gain of a structure at the ASHRAE 97.5% design outdoor temperature and 75°F dry bulb 62°F wet bulb indoors (expressed in Btu/hr).

Diversified Peak Demand - The amount of power draw realized by the utility during their peak period for a particular end use for the customers that have that end use.

Dry Bulb Temperature - The temperature measured using a common thermometer.

Duct Blaster™ - Similar to a small blower door, this device is used to test the leakage of a duct system.

Duct Leakage (Exterior) - The leakage of the duct system to outside the structure.

Duct Leakage (Total) - The leakage of the duct system including unintentional leakage to inside and outside the structure.

Duty Cycle - The percentage of time that an end use is on during a specified period.

EER - The Energy Efficiency Ratio. The capacity of an air conditioner (in Btu/hr) divided by the electrical input (in watt hours).

Effective Capacity - A rating of the systems true operating capacity adjusted for duct losses experienced.

Evacuation - The removal of gases from a closed refrigerant system until the pressure is below atmospheric pressure.

Evaporator - The heat exchanger (coil) in a refrigerant system that removes heat thus boiling the refrigerant.

Flow Hood - A calibrated air flow measurement device.

Group A - The group of customers shown through Model P to have their air conditioners off during peak.

Group B - The group of customers shown through Model P to have their air conditioners cycling on and off during peak due to thermostatic control.

Group C - The group of customers shown through Model P to have their air conditioners running continuously during peak, but could be in Group B if some reduction of load or increase of effective capacity were implemented.

Group D - The group of customers shown through Model P to have their air conditioners running continuously during peak.

Half -Nelson - A methodology used to estimate the ratio between total supply leakage and total return leakage based on pressure measurements with all registers blocked.

HVAC - Heating, Ventilating and Air Conditioning.

Indoor Coil - The evaporator coil, located at the air handler, on an air conditioning system.

Latent Capacity - The amount of moisture removed by a cooling appliance.

Micron Gauge - A calibrated instrument used to measure vacuum in a closed refrigerant system.

Model P - A model that examines occupant behavior patterns to make adjustments to peak effects of various DSM options.

N factor - The infiltration/leakage coefficent. A conversion factor from blower door measured leakage(CFM 50) to modeled average infiltration rates, This factor is derived from a simplification of the LBL model.

Overcharge - The condition of an air conditioning system that has more refrigerant than is specified by the manufacturer .

Package Unit - An air conditioning system with all major components located in one cabinet.

Pascal - A small metric unit of pressure. One pascal is 0.000145 PSI.

Pressure Pan - A shallow pan placed over a supply or return grill with a blower door operating. The pressure measured at the pan is a qualitative indication of duct system leakage.

Return System - The portion of the duct system used to return air from a structure to the air handler.

Saturation - The temperature/pressure at which both the refrigerant liquid and vapor are present in equilibrium

SEER - The Seasonal Energy Efficiency Ratio, a comparative measure of an air conditioners efficiency, much like EER but rated at a much cooler outdoor temperature.

Sensible Capacity - The amount of heat added to or removed from a structure measured by dry bulb temperature.

Split System - An air conditioning system that has the condenser remotely located from the evaporator.

Static Pressure - A measure of pressure that is equally exerted in all directions within a given point of the duct system.

Subcooling - The difference in temperature between liquid refrigerant and saturated refrigerant at the same pressure.

Superheat - The difference in temperature between refrigerant vapor and saturated refrigerant at the same pressure.

Supply System - The portion of the duct system used to deliver conditioned air from the air handler to individual rooms.

Hourly Temperature Bins - The number of hours during the season that the outdoor temperature falls within the specified range.

Thermostatic Expansion Valve (TXV) - A refrigerant metering device that adjusts the flow of refrigerant to maintain a constant superheat at the exit of the evaporator coil.

Ton of Cooling - The amount of heat required to melt a ton of ice at 32°F in one hour (12,000 Btu/hr).

Unconditioned Space - The part of a structure that is not intentionally heated or cooled by the heating or cooling equipment.

Undercharge - The condition of an air conditioning system that has less refrigerant than is specified by the manufacturer.

Weighing in Charge - A method of charging refrigerant systems by using a scale.

Wet Bulb Temperature - The temperature measured by a thermometer covered with a wet wick with air blowing across it. The measured temperature is lower than the dry bulb temperature and is a measure of moisture in the air.

APPENDIX A: SUMMARY OF RELATED STUDIES

A number of previous studies have been conducted on duct systems and air conditioners in both new construction and retrofit applications. These studies were completed by Cummings et al., Hammerlund et al., Jacobson et al., Jump and Modera, Neal, Proctor et al. (1990) and Proctor (1991). Five of these studies included field monitoring of energy usage (Cummings et al., Jacobson et al., Jump and Modera, Proctor et al. (1990) and Proctor (1991). All but one of these studies examined impacts of retrofit improvements to the air conditioners and/or duct systems on previously constructed houses, while Hammerlund et al. dealt solely with newly constructed homes.

Cummings et al.

In a comprehensive study of 91 "typical" Florida houses Cummings et al. (1990) studied the energy effects of duct leakage. Blower door tests were performed on 63 houses to determine the impact of duct leakage on infiltration rates in the house. Duct repairs were made on 25 houses and 24 of these houses had their cooling energy usage monitored before and after the duct repairs.

Tracer gas testing found that infiltration rates for the houses were four times greater when the air handler was operating than when it was off. The average Air Changes per Hour (ACH) for the 91 houses was 0.21 with the air handler off and it increased to 0.93 when the air handler was turned on. Tracer gas testing found that the Return Leakage Fraction (RLF) averaged 10%. Thirty percent of the houses tested had an RLF of greater than 10%, with the majority of the leakage coming from unconditioned attic space.

The blower door testing performed on 63 houses indicated that on average 11.7% of the total house leakage area was located in the duct system. While the duct system accounted for less than 1% of the volume of the houses, it was determined to cause 71% of the total house infiltration when the air handler was on.

In the 25 houses that received duct sealing work, it was found that on average 16% of the blower door measured house leakage area was attributable to duct leakage. Blower door testing indicated that the retrofit duct repairs reduced the average duct leakage by 68%. Tracer gas testing determined that the return leakage fraction for these homes were reduced from an average of 16.7% to an average of 4.5%. Measured cooling energy usage showed that 22% of the cooling energy usage was attributable to the duct leakage and an 18% reduction in cooling energy usage was realized after duct repairs were performed.

Hammerlund et al.

In an extensive study of newly constructed residences in the Los Angeles area 66 apartments and 12 houses with ducted heat pump systems were examined for installation practices and system performance[6]. Each residence was tested for problems in three major areas; duct leakage to the exterior, air flow through the indoor coil and refrigerant charge.

Even though the residences examined were newly constructed and most had received a utility financial incentive for installation of energy efficient heat pumps, significant deficiencies were found in all three areas.

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[6] None of the houses tested were over two years old.

The predominate problem in single family residences was duct leakage. The blower door testing performed on these houses indicated that the vast majority of the homes had excessive duct leakage over what could be reasonably achieved. Over 85% of the houses had supply leakage in excess of 50 CFM_{50} and 90% of the return systems had duct leakage in excess of 50 CFM_{50}. This duct leakage resulted in an increased cooling load of approximately 30%.

Low air flow through the indoor coil and incorrect charge were also found to be a problem in these residences. Only 30% of the houses tested had air flow within the manufacturers specifications for proper air flow. This low air flow made the checking of charge by manufacturers recommended procedures impossible on all but five of the houses. Of those five houses one was undercharged and the remaining four were overcharged.

The duct leakage to the exterior of the building was considerably lower on the multifamily residences tested. This was due to both shorter duct runs and lower operating pressures typical of multifamily residences. However, low air flow through the indoor coil proved to be a more serious problem in the multifamily residences tested. Less than 15% of the units tested had the correct air flow through the indoor coil. Two thirds of the heat pumps in the multifamily residences were incorrectly charged with 61% being overcharged and 8% being undercharged.

With interactive effects taken into account, the average energy savings opportunities for cooling single family residences was 38% and multifamily residences had average cooling savings opportunities of 18%.

Jacobson et al.

This study of 250 single family residences evaluated the potential for implementing the lessons learned in previous Appliance Doctor™ studies to full scale production programs. The retrofit program focused on the problem areas of duct leakage to the exterior, low air flow through the indoor coil, and incorrect refrigerant charge.

The project was split into two groups of air conditioned homes; randomly selected customers and high bill complaint/high AC usage customers. Thirty of the houses were monitored pre and post retrofit to evaluate the impact of the retrofit measures.

The study design was comprised of contracting, marketing, training, diagnosis and repair, and quality assurance components.

Contracting was structured in a fixed cost performance contract with two local HVAC contractors. Job completion was based on successful completion of set criteria and payment was made after each job successfully passed a technical review process. The fixed fee contracting structure proved to work well as long as the technical process review happened in a timely fashion.

Marketing was targeted to customers that were projected to have high seasonal cooling usage based on billing history data. A "seasonal swing" algorithm was created to indicate those customers with high seasonal cooling usage. Customers were offered services at a fraction of the cost they would normally incur for the repairs and their total end cost for the service was dependent on the services received. All customers received duct sealing but, not all customers needed air flow or charge repair so the end cost to the customer was prorated based on the services received. The straight forward direct mailing piece that was mailed out resulted in all 250 slots for the project being filled within two days. A customer survey showed that customer satisfaction was high (rated 4.4 on a scale of 5) and over half of the customers felt their system was operating more efficiently and would result in lowered energy costs.

The crew configuration that worked best was a two person duct sealing crew equipped with a blower door and other diagnostic tools followed by an HVAC specialist to service the air conditioner. The testing of the systems indicated significant problems with duct system leakage.

Eighty seven percent of the high bill complaint customers had duct leakage in excess of 150 CFM_{50} while 80% of the randomly selected had duct leakage in excess of 150 CFM_{50}. Low air flow through the indoor coil was determined to be a problem on 50% of the high bill complaint customers and 29% of the random customers. Problems with undercharged units were nearly equal (36% of the high bill complaint customers and 41% of the random customers). No overcharged units were detected in the random group while 27% of the high bill complaint group had overcharged units.

Submetering showed a cooling energy savings of 16% for the high bill complaint customers (21.5% if undercharged units are excluded) and 9% for the random customers. High usage customers proved to have a higher occurrence of problems with their systems and realized a greater benefit from the services provided. The "seasonal swing" methodology proved to be reliable at indicating customers likely to benefit from the program.

Quality assurance and training played an important role in the project and proved to be successful in providing a means for insuring quality work from HVAC technicians. The testing protocol, technical process review and prompt feedback continually improved technician performance and understanding of the program. Technical process review and feedback were a crucial control feature of the project that were required to be delivered in a timely fashion.

Jump and Modera

This study examined the combined energy effect of duct leakage retrofit repair and the application of additional duct insulation on thirty houses with attic located duct systems. The energy effects were monitored on a total of 5 houses during the summer season and 6 winter season houses. The 6 winter season houses were all equipped with electric heating systems. Short term (~ 2 week) monitoring took place for both pre and post retrofit periods.

The extensive diagnostic testing included duct leakage testing, system air flow measurement, and measurement of normal operating static pressures within the duct systems. The monitoring included temperatures throughout the duct system, attic, and outside, as well as power consumption of all significant HVAC system components.

Testing found that supply and return leakage areas were nearly equal. However the return system leakage reduction averaged 73% while the supply system leakage reduction was only reduced by 56%. The greater success in sealing the return system was attributed to the leakage being concentrated in a few sites. Overall, approximately 64% of the duct leakage was eliminated and this sealing work reduced the house leakage area by approximately 14%. Increasing the duct R-value to an R-6 on both the plenums and the individual duct runs reduced conduction losses by an average of 33%.

Neal

Neal performed an investigation into measured system performance on ten central air conditioning systems in North Carolina. The study was designed to compare the actual performance of the equipment to the manufacturers rated performance.

This study found that on average the air conditioners were performing at 70% of rated efficiency. Four of the ten units did not have proper of air flow through the indoor coil and five of the ten were incorrectly charged. It was noted that all of the units examined had at least one efficiency or service life problem.

Proctor et al. (1990)

Pacific Gas & Electric Company sponsored an investigation of heat pump operating efficiency for high bill complaint customers in the winter of 1989. This study was designed to identify major problems existing with heat pump installations and to design a system to correct those deficiencies. The study focused on the problem areas of low air flow through the indoor coil, incorrect refrigerant charge, excessive use of back-up heat strips, other control problems, shell leakage, and duct system leakage.

The study examined 51 heat pumps in 49 houses. Each of the houses was visited by a heat pump technician that used a set procedure to diagnose and repair problems with the heat pump. To quantify problems with the duct system and the building shell each of the houses was inspected with the use of a blower door. Three of the retrofitted houses were chosen for pre and post retrofit short term monitoring.

Technician visits identified at least one major problem in over 90% of the houses tested. Seventy three percent of these houses had received a recent visit by professional HVAC service personnel that had not found nor solved the problems identified in the study. Table A-1 lists the major problems found at the sites.

Table A-1
Problems Identified by House

Problems	Number of Houses with Problem	Problem Solvable Through Program
Diffuse Duct Leakage > 150 CFM_{50}[7]	33	25
Low Air Flow	24	19[8]
Incorrect Charge[9]	16	16
Disconnected Ducts	16	14
Refrigerant Leaks	10	10
Recirculation Through Outdoor Coil	9	0
Auxiliary Heat on First Stage	3	3
House Leakier Than 0.75 ACH	15	15

Savings projections indicated that duct leakage repair was the best option for lowering the customers high seasonal energy usage, followed by refrigerant charge correction, sealing of shell leakage sites , installation of auxiliary strip heat cut-outs , and correction of low air flow.

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[7] Duct leakage was measured after all disconnected ducts had been repaired.
[8] Low air flow on these units were caused by restrictive duct design. Modification of the duct system through adding runs or increasing duct sizing was outside the scope of this program.
[9] The methodology used for checking charge in this study did not indicate units that were overcharged. Additionally only units that could be brought to correct air flow were tested for charge.

Proctor (1991)

A comprehensive study was commissioned by Pacific Gas & Electric Company during the summer of 1990 on 15 houses in Fresno, California to determine the potential energy and peak reduction savings of a program for residential air conditioners. During the study all houses were monitored for energy usage for a period preceding repairs and after repairs. The majority of the customers selected were high bill complaint customers.

All 15 of the houses had at least one major problem with the air conditioner or the duct system. Ninety percent of the homes had duct leakage in excess of 150 CFM_{50}. Duct leakage accounted for 14.7% of the total building shell leakage area. The average cooling load increase due to the duct leakage was 25%. The average retrofit duct leakage reduction achievable was 60%, with a corresponding monitored cooling energy savings of 18%.

Sixty seven percent of the systems had low air flow through the indoor coil. Cleaning resulted in an average increase in air flow of 16% . Fifty six percent of the air conditioners had an improper level of refrigerant charge.

All of the houses in the study experienced at least a 10% reduction in monitored cooling energy usage and a number of the houses experienced savings in excess of 30%.

Duct sealing peak effect studies

Valid estimation of peak day electrical usage for residential air conditioners and their duct systems are intrinsically difficult due to the fact that the evaluator is trying to predict an event that occurs rarely and is usually outside the measured data set. Additionally peak usage of air conditioners is driven by numerous variables (i.e. occupant behavior, outdoor temperature, relative humidity, time of day, sky cover, etc).

Proctor (1993) examined six analytical models using submetered data from the Appliance Doctor™ Pre-Production Project to analyze the strengths and weaknesses of the models at estimating peak reduction. All six models showed consistent results that peak reduction occurred in the early evening hours (local residential distribution peak) when duct systems were sealed. Peak reduction in the early afternoon hours (system peak) could not be proven due to the small size of the sample.

Cavalli and Wyatt (1993) examined a sampling of 240 submetered air conditioners from the PG&E Model Energy Communities Project. This study was designed to determine if there was any peak effect attributable to: 1) duct sealing on residential air conditioners and 2) early replacement of air conditioners that were oversized (as determined by ACCA Manual J) and had low rated EER's (this group also received duct repairs).

The results showed negligible peak operating impact from duct sealing of 0.04 kW. Replacement of air conditioners with correctly sized more efficient air conditioners was shown to be effective at reducing the peak operating impact by approximately 1.4 kW. The authors indicate the results of their analysis is limited by the fact that the data was from a cool summer where the maximum temperature never reached 100°F.

Jacob and Zebedee (1994) examined the peak impact of duct sealing using metered data from the Florida Power Corporations duct sealing program. The analysis showed an estimated average peak demand savings of 0.5 kW.

These three studies show that there is no absolute agreement on peak reduction attributable to duct sealing alone. Together however, they support the point that duct sealing combined with sizing reductions will reduce peak.

APPENDIX B: COMBINED MODEL AND DATA SOURCES

The combined model presented in this report is composed of three primary sub-models: a duct loss model, an air conditioner performance model, and a residential air conditioner peak load model.

A schematic of these three models is shown in Figure B-1

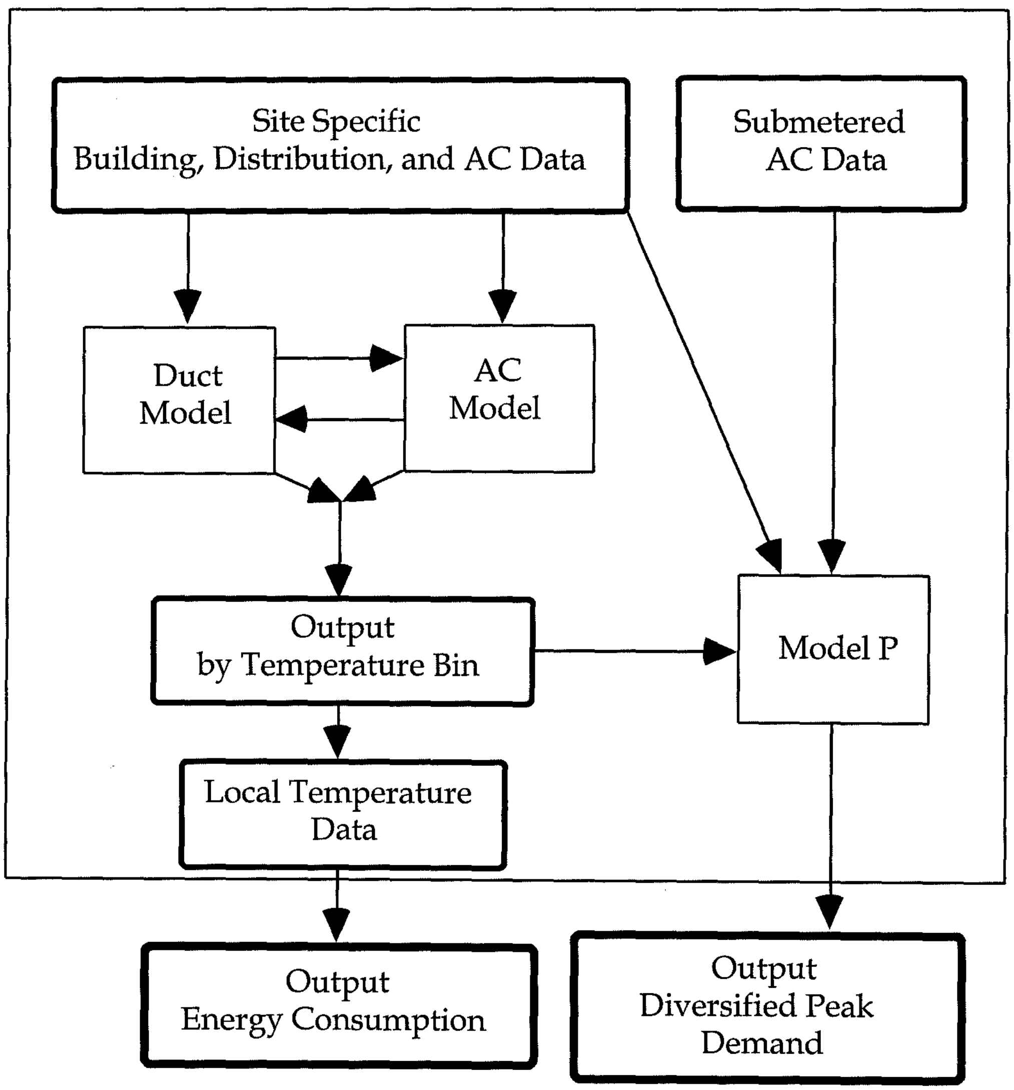


Figure B-1
Combined Model Schematic

Duct Loss Model

The duct loss model includes the impacts of direct leakage losses, induced building infiltration losses, and conductive losses. The model characterizes these losses as a loss of effective system capacity. The duct model also calculates return plenum temperatures and average supply air temperatures based on leakage and conduction rates and indoor and supply plenum temperatures.

The basic model including leakage and infiltration effects is the work of Palmiter (Palmiter and Bond, 1991). Proctor Engineering Group has added the effects of conduction and energy recovery (when supply leakage is mitigated by nearby return leaks and other recovery mechanisms) into that model.

The duct loss model is a steady state model. The losses are scaled to the duty cycle of the air conditioner for each temperature bin.

Air Conditioner Model

Version 1.2 of the model is a dry coil model that calculates changes in capacity and efficiency due to:

- Outdoor temperature
- Refrigerant charge (capacity and efficiency generally peak at proper charge, but the effect is dependent on other variables)
- Return plenum dry bulb temperature
- Air flow across the indoor coil

The model also calculates the supply plenum air temperature based on the return plenum temperature, system capacity, and air flow rate.

The model draws on a variety of sources including:

- Laboratory tests of air conditioners with charge varied from 20% below to 20% above proper charge (Farazad and O'Neal, 1988 and 1989). These tests were conducted with outdoor coil inlet air temperatures from 82°F to 100°F.
- Simulation runs by Proctor Engineering Group for higher outdoor temperatures and lower indoor wet bulb conditions with MODCON, the air conditioner simulation program of Oak Ridge National Laboratory (Rice, 1991).
- Data gathered from major manufacturers on performance of air conditioners under nearly dry coil conditions.

The air conditioner model is a steady state model. The consumption is scaled by the duty cycle of the air conditioner for each temperature bin with an adjustment for cycling losses.

Modeled Cooling Loads

Building shell loads for the combined energy consumption model were based on a constant temperature setting[10] of 78.9°F. The design load is separated into four components: solar gain, conductive gain, infiltration, and internal gains. The load for a given temperature bin is then calculated as a function of outdoor temperature (including a linear component for conduction and non-linear component for infiltration), average sunshine at that temperature, and constant internal gains.

10 For the diversified peak load model (Model P) only a portion of the units were modeled as "constant thermostat setting" (Groups B and C).

Peak Load Model (Model P)

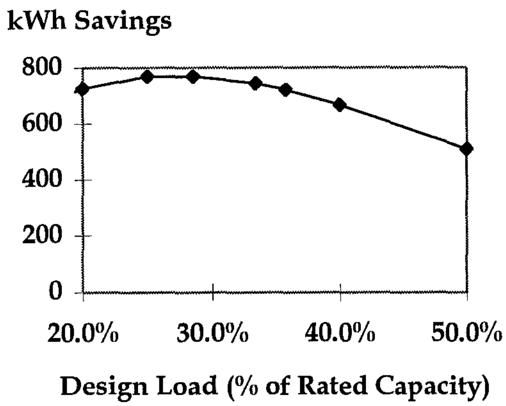
Model P includes all the impacts both known and unknown that effect occupant behavior to produce a given duty cycle at peak. These effects are nested in the empirical base for Model P - submetered air conditioner data from peak hours. The output from Model P is the diversified demand of the residential air conditioners under varying scenarios.

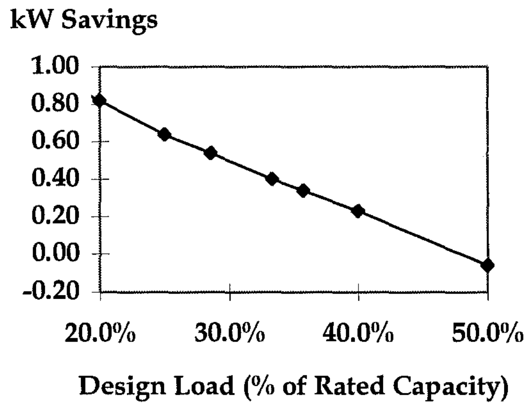
The diversified demand is calculated as the weighted sum of the demands of the four groups. The demand of the four groups are:

- Group A air conditioners have no demand at peak
- Group B and C air conditioners have a peak demand that is dependent on the ratio of the cooling load to the effective capacity of the unit (duty cycle). Under different scenarios, the duty cycle will change.
- Group D demand equals their modeled connected load. The connected load (which is dependent on outdoor temperature, return plenum temperature, refrigerant charge, and indoor coil air flow) is an output from the combined air conditioning and duct model adjusted by the relative loads.

Model P was developed by Proctor Engineering Group in order to improve predictions of peak effects from alternative technological options. The data used to build Model P for this study came from a sample of twenty randomly selected houses from an existing SCE load research project. Patterns from the five hottest days of 1994 were analyzed and characterized into the Model P groups.

APPENDIX C:
SENSITIVITY ANALYSIS - RELATIONSHIP TO COOLING LOAD





The modeled kWh savings for these homes is relatively independent of the relationship between load at design and the rated capacity of the air conditioner. The peak reduction however is highly dependent on this value. Homes with oversized air conditioners have a much higher potential for peak reduction than homes with properly sized units.

APPENDIX D: HOUSE DATA

Table D-1
House Data

	Duct Leakage CFM50			Leakage Fractions Supply		Leakage Fractions Return		Air Flow/ton		Capacity	Shell Lkg.
Unit ID	Pre	Post	Diff	Pre	Post	Pre	Post	Pre	Post	Btu/hr	Pre
1	756	500	256	12%	8%	20%	11%	N/A	N/A	52500	2800
2	1132	661	471	33%	19%	26%	11%	200	255	59000	2900
3	466	104	362	8%	3%	8%	1%	340	352	48000	2200
4	1299	745	554	24%	17%	66%	50%	219	220	60000	2800
5	951	100	851	55%	6%	8%	0.4%	459	459	34200	2050
6	341	144	196	5%	4%	14%	3%	278	321	56000	2350
7	694	524	170	22%	16%	13%	4%	349	360	56000	2500
8	295	187	108	12%	8%	15%	10%	279	282	43000	1650
9	787	422	365	18%	10%	33%	17%	301	299	55500	2700
10	816	781	35	10%	14%	98%	28%	215	367	44000	4300
11	155	75	79	10%	6%	8%	2%	295	295	42000	3350
12	273	151	123	4%	3%	14%	6%	407	407	42000	
13	264	127	137	13%	8%	15%	3%	456	456	28000	3200
14	505	173	332	8%	7%	31%	3%	285	334	42000	
15	551	330	221	13%	7%	31%	22%	304	311	44500	2400
16	675	347	328	23%	14%	4%	0%	366	366	59000	2700
17	251	147	104	13%	9%	4%	1%	490	490	28000	2000
18	345	269	77	14%	12%	38%	31%	299	307	18000	
19	1011	785	226	23%	22%	51%	35%	258	264	49000	5100
20	1000	680	320	32%	26%	41%	25%	245	245	49000	
21	921	771	150	30%	24%	29%	33%	274	274	60000	9510
22	669	517	152	31%	25%	29%	27%	208	208	60000	
23	317	118	199	12%	4%	15%	3%	248	343	45000	3700
24	622	356	266	9%	3%	55%	23%	241	324	45000	
25	1079	582	497	31%	15%	16%	6%	229	284	60000	3700
26	350	184	166	5%	2%	10%	5%	264	292	47000	2200
27	565	388	177	29%	22%	2%	1%	400	400	60000	2700
28	788	320	468	32%	14%	45%	22%	294	294	45000	4700
29	871	372	499	26%	14%	46%	24%	264	264	57000	
30	379	229	150	12%	8%	9%	4%	N/A	N/A	58000	2150
31	427	109	318	11%	3%	5%	0.5%	263	332	40000	1850
32	603	137	466	17%	4%	0.5%	0.2%	355	355	48000	1800
33	469	155	314	10%	5%	4%	2%	414	414	35000	1650
34	286	143	142	7%	4%	7%	4%	253	258	58500	3250
35	269	168	101	11%	9%	15%	6%	280	280	48000	4100
36	367	171	196	12%	11%	33%	7%	249	249	39500	
37	339	198	141	5%	4%	15%	8%	N/A	N/A	46729	2200
38	1017	249	767	47%	23%	37%	0.3%	226	226	60000	2550
Mean	603	327	276	18.2%	10.9%	23.9%	11.5%	300	320	47959	3035
Median	558	239	210	12.8%	8.6%	15.0%	5.7%	279	307	48000	2700