Duct Testing and Repair Programs

Profile #51

Executive Summary

Duct testing and repair is one of the most exciting new areas for potentially huge energy savings. Recent studies and pilot programs show that these savings can be realized in southern and northern latitudes... and that the per home savings can be as high as 8-10% of total household energy use, or as much as 10-15% of household electrical use. In short, duct testing and repair represents one of the newest and largest gold mines for residential energy savings.

The recent focus on duct testing and repair is really the brainchild of three independent energy analysts. John Tooley and Neil Moyer of Natural Florida Retrofit had the insight that a tremendous amount of energy is wasted as a result of leaky ducts. They also gained the respect and support of Jim Cummings of the Florida Solar Energy Center who was simultaneously working on the same concept. Fortuitously, the three teamed up and began to champion the cause with the critical financial support of the Florida Energy Office. They found that leaky ducts are a common, if not universal problem in Florida.

This profile, unlike others in The Results Center's 1992 and 1993 Profile Series, does not focus on any one specific utility, but instead presents brief descriptions of the "founding fathers" of duct testing and repair (the Florida Solar Energy Center and Natural Florida Retrofit), then some of the base concepts involved with duct testing and repair, and then presents the experiences of several utilities to date in this field. These utilities include The City of Lakeland (FL) Electric and Water Utility, Florida Power Corporation, Florida Power and Light, Pacific Gas and Electric, and Duke Power Company.

As alluded to above, repairing leaky ducts bears a great potential for energy savings (both electric and gas and other home heating fuels as well.) But repairing leaky ducts can have significant air quality benefits as well. Often leaky duct returns, which are under negative pressure or a mild vacuum, pull poor quality air from attics, garages, and basements. Tightening these ducts can thus enhance indoor air quality. The flip side of this equation is that by reducing leakage from a home there is a potential to upset delicate pressure balances, and with it the chance of exacerbating safety issues related to appliances that rely on combustion, such as gas hot water heaters. Thus care has to be taken and most utilities perform combustion safety tests before and after their duct repair efforts.

One of the great ironies of this emerging field is that ducts ought to be installed correctly in the first place. If they were, there would be much less need for costly and time-consuming retrofits. PG&E's new duct testing and insulation program discussed in this profile includes a "High Performance Ducts" component in its residential new construction program. As such, builders can earn incentives for installing and testing duct systems in accordance with requirements set forth by PG&E, obviating the need for later repairs.

Duct Testing and Repair Programs

Organizations:	Florida Solar Energy Center and Natural Florida Retrofit Inc.
Sector:	Primarily residential, but research is being conducted in the commercial sector
Measures:	Repair of leaks in duct systems
Mechanism:	Duct systems are tested and areas of leakage are identified by qualified contractors. Duct repairs are made using mastic and fiberglass mesh. Combustion safety testing is performed as part of the duct testing and repair process.
History:	FSEC and NFR began investigating duct testing and repair in 1985 and 1986. Utilities have been implementing system-wide programs since 1991.

Potential Savings per Home

Annual energy savings:	1,400 kWh
Winter peak capacity savings:	1.6 kW

Conventions

For the entire 1993 profile series all dollar values have been adjusted to 1990 U.S. dollar levels unless otherwise specified. Inflation and exchange rates were derived from the U.S. Department of Labor's Consumer Price Index and the U.S. Federal Reserve's foreign exchange rates.

The Results Center uses three conventions for presenting program savings. **Annual savings** refer to the annualized value of increments of energy and capacity installed in a given year, or what might be best described as the first full-year effect of the measures installed in a given year. **Cumulative savings** represent the savings in a given year for all measures installed to date. **Lifecycle savings** are calculated by multiplying the annual savings by the assumed average measure lifetime. **Caution:** cumulative and lifecycle savings are theoretical values that usually represent only the technical measure lifetimes and are not adjusted for attrition unless specifically stated.

FSEC and NFR Overview

Since 1986, researchers at the Florida Solar Energy Center and Natural Florida Retrofit have been conducting significant research and development work pertaining to duct testing and repair. These two groups have been instrumental in promoting interest in duct testing and repair and encouraging the recent proliferation of utility programs throughout the U.S. that focus on this heretofore untapped gold mine of energy savings. This section presents a brief overview of the Florida Solar Energy Center and Natural Florida Retrofit.

The Florida Solar Energy Center (FSEC) is a statewide research institute operating within the state university system under the University of Central Florida. FSEC was established in 1974 "to look at energy alternatives for the citizens of Florida." The Center has been thriving in the last few years, with 120 staff, more than any other year.[R#1]

In 1992, FSEC received $3 million in state support. This funding was augmented by $6 million in contracted research and development work. [R#1]

Current major FSEC activities include the following:

- A decade-long photovoltaics R&D program focussing on development and integration of solar systems into utility, residential and stand-alone applications.
- Development of new thin-film photovoltaic technologies.
- R&D on advances in housing technologies to increase quality, efficiency and affordability.
- Development of innovative cooling systems augmented by heat pipes and desiccants.
- R&D on solar-hydrogen production, storage and utilization.
- Research on alternative transportation fuels, including hythane, natural gas and methanol.
- Development of solar-related technologies for detoxifying hazardous wastes.
- Refinement of solar water heating systems for both institutional and residential applications.
- Development of computer software to aid energy research.
- Education and training of students and professionals.[R#1]

The Center publishes and distributes a wide variety of publications for energy consumers as well as the academic, research and governmental sectors. FSEC's library, which is open to the public, holds one of the most extensive collections of alternative energy-related documents in the U.S.[R#1]

FSEC has developed a variety of unique demonstration and research facilities at its 16-acre research complex in Cape Canaveral, on Florida's Atlantic coast. In 1994, FSEC will relocate to new facilities at the University of Central Florida Brevard Area campus in Cocoa, about 10 miles from Cape Canaveral. In addition to providing much-needed laboratories, the complex will be a "living" example of the new energy concepts that are the subject of FSEC research. The New Energy Center will also demonstrate the remarkable savings available from solar and energy-efficiency technologies.[R#1]

Natural Florida Retrofit, Inc. (NFR), based in the Orlando, Florida area, specializes in energy conservation contracting, consulting, and research with clients throughout the nation. NFR was founded in 1982 as a service company with a desire to investigate and develop solutions to residential housing problems in the areas of health and safety, durability, comfort and affordability.[R#17]

As a result of NFR's research and innovative solutions, its principals have received the Joule Award for "Excellence in Innovation," presented by the Energy Efficient Building Association. Furthermore, in 1990, NFR's principals received the Florida Governor's Energy Award for their work in forced air distribution diagnostics.[R#17]

In 1993, NFR is actively involved in several projects:

- Development of duct leakage repair demand-side management program design, implementation, training and quality assurance for numerous utilities across the nation.
- Research and development on solutions to mechanical air distribution and interacting relationships, (MAD-AIR), both in residential and commercial buildings.
- Education and training on applied building science.
- Development of sustainable consistent application of applied building systems.
- Development of a builders' field guide that promotes energy efficiency and environmental responsibility in view of the marketing, cost, and liability realities of the existing home building industry.
- Lead trainers for the Duct Doctoring course at the Florida Solar Energy Center.[R#17] ■

Program Overview

DUCT REPAIR PRINCIPLES AND METHODS

In 1985 and 1986, researchers at the Florida Solar Energy Center and Natural Florida Retrofit became simultaneously interested in the energy impacts of duct system leakage. Later, the two entities, in conjunction with the City of Lakeland Electric and Water Company, entered into a cooperative project funded by the Florida Energy Office to investigate the impacts of duct leakage in central Florida homes. The study of 160 homes in central Florida revealed that cooling energy savings of 17.2%, equivalent to annual savings of about 1,400 kWh per home, could be realized with duct repairs. As a result of this work, many utilities have started full scale and pilot programs, or are incorporating duct testing and repair into their existing residential audit and weatherization programs.

The duct system is tested using a blower door. First, the house is depressurized and its airtightness measured. Next, all registers in the house are covered and the house is again depressurized using the blower door. The difference in airtightness with the registers covered represents the percent of house leak area that is in the duct system. To determine the approximate location of the duct leaks, the house is pressurized with the blower door, and a smoke generator is held near each supply register or return grill (with the air handler off). Movement of the smoke through the registers or grills indicates a nearby leak in the duct. Finally, to determine more precisely the location of duct leaks, the air handler is turned on and the duct system is visually inspected with the aid of the smoke tester.

Duct repair is typically done using mastic and fiberglass mesh which provides the structural integrity to duct work that duct tape cannot provide. Mastic is a glue-like substance that has good structural characteristics and is able to stick in a variety of circumstances. The fiber adds to the structural strength of the duct seal. After repairs are made the blower door testing is repeated to ensure that all leaks have indeed been repaired.

When done properly, duct repair will improve indoor air quality and home health and safety, while at the same time reducing electric demand and energy use. In some cases, duct leaks are so large that air conditioning and heating systems cannot keep up with the cooling or heating load. This situation may put undue demand on the heating and cooling system, decreasing its useful life. In fact, duct leaks often increase heating and cooling loads by 15% to 50%.[R#5] Furthermore, return duct leaks may allow the air handling system to draw in pollutants from the attic, the garage, the ground, or the outdoors, causing deterioration of indoor air quality. In humid areas, duct leaks can cause mold, mildew, and condensation, by drawing additional moisture into a home. Through the duct testing and repair programs, utility customers are educated on the impacts of duct leaks and afforded the opportunity to significantly decrease their heating and cooling energy use while at the same time improving their home's environmental health.

Special consideration must be taken when looking at duct leakage and repair in homes with combustion appliances. Both duct leakage and duct repair may cause depressurization of the home. When depressurization occurs, combustion fumes may be drawn into the home, as opposed to going up the chimney or vent stack, thus contributing to potentially dangerous indoor air quality problems.

As a precaution, combustion safety testing is done both before and after duct repair to establish whether any safety concerns exist and whether corrective measures leave the house safe. Contractors should be trained to look for potential combustion appliance problems and should not repair duct leaks unless their concerns about combustion appliances are also addressed. The combustion safety check includes measurement of carbon monoxide levels, draft testing, and pressure measurement in combustion appliance rooms including fireplaces and wood stoves.[R#5]

UTILITY PROGRAMS

The City of Lakeland Electric and Water Company's project with the Florida Solar Energy Center and Natural Florida Retrofit was funded by the Florida Energy Office. For the study, 160 homes were selected from among 600 respondents to a mailing describing the project. All 160

homes were tested for duct leaks and 50 homes received duct repairs free of charge. Participants whose homes were selected for duct repair agreed to maintain their thermostats at constant temperature, to record any unusual behavior that could affect their cooling-use, and to read the end-use meters daily for four weeks before and after repair.

The results of this study were published in 1991 and are discussed in detail in the Evaluation section of this profile. The study calculated that if duct leaks were repaired in each of the three million electrically heated homes in Florida, potential winter peak demand savings of 4,949 MW could be achieved.[R#6]

Florida Power Corporation's Duct Test and Repair Program began in 1991, after several years of pilot projects, and represents the first major utility effort to include duct repair in DSM. Early on, FPC indicated an interest in the research project conducted by the Florida Solar Energy Center and Natural Florida Retrofit in conjunction with the City of Lakeland Electric and Water. As the research was ongoing, FPC maintained contact with the researchers and became convinced that a duct testing and repair program could achieve significant savings.[R#9,11]

The program covers one-half of the cost of an inspection and repair, with maximum payments of $25 for an inspection (additional units may be inspected with FPC covering one-half the cost, to a maximum of $15) and $100 for duct repair. In just two years, FPC's Duct Testing and Repair program has reached more than 10,000 eligible customers, and completed repairs in nearly 8,900 homes, with winter peak demand savings of more than 9 MW.

All personnel involved with FPC's Duct Testing and Repair program are required to have attained rigorous technical qualifications. Contractors and inspectors associated with the Duct Testing and Repair program are all certified through an intensive six-day course offered by the Florida Solar Energy Center. The course covers both diagnosis and repair of duct leaks, and goes into detail regarding building science, the impacts of duct leakage, testing methods, and repairs.[R#9,10,11]

Florida Power & Light (FP&L) initiated a similar program later in 1991. FP&L was intrigued by the potential energy and capacity benefits of thermal distribution repair as detailed by the FSEC research, and the huge potential market in the utility's service territory convinced FP&L to pursue a duct repair program.

FP&L also requires all participating contractors to receive rigorous training from a source approved by the utility. Originally, FSEC's training program was utilized, but to serve its large service territory, the utility has also contracted with another firm to provide training. Anyone involved in either testing or repair of the duct systems receives the same training to ensure that all parties have a full understanding of the issues.

The program has been implemented for over one year. Testing and repair of the duct work is performed by different organizations to provide implicit quality control. In fact, FP&L has worked to develop the necessary in-house expertise to provide the testing. All repair work is done by contractors that have met the training requirements. During the program's first year, 100% of the repairs were checked by the utility. As a result, many of the contractors have begun to check repairs using the same equipment as FP&L before leaving a site to ensure that the project will pass inspection, and to obviate the need for a costly return visit that is required by the utility on failed projects.

FP&L feels the program will move the thermal distribution market significantly in its territory. An evaluation of the program is underway, and is likely to be completed in October of 1993. FP&L estimates that 40,000 houses have been tested this year without any significant marketing effort by the utility. The utility feels that such a marketing effort could heighten customer awareness and drive the program in the future, but does not feel such an effort to be necessary at this time given the current participation rates among its customers and the increased activity by the contracting community in this area.[R#14]

In late 1993 **Pacific Gas and Electric** plans to implement its Duct Repair and Insulation Rebate program after gaining much experience with pilot programs. ☞

PG&E's pilot was conducted in 1990 and 1991, and included approximately 250 homes in the Fresno area, where air conditioning electricity demand is significant. Participation was solicited through direct mail and interest in the program was great. Average savings for participants in the pilot was 24% of air conditioning electricity use. The pilot results also revealed that homes with higher air conditioning use had higher percent savings.

Based on the results of the pilot program, the system-wide program will be targeted at customers with annual electric air conditioning demand greater than 2,000 kWh. Participants will be required to pay a portion of the cost to test, repair, and seal their duct systems. The customer portion of the cost is anticipated to have a payback period of three years. PG&E has assumed savings of 20% will be realized in each home, with about 1,000 homes in two cities participating in 1993, expanding to 5,000 to 10,000 participants throughout the system in 1994.

The program will be implemented by contractors selected on a competitive bid basis, after they complete a paid three and a half week PG&E training session. Contractors will use a duct blaster, which blows directly into the return duct with the supply registers sealed. Flow through the duct blaster is measured on a cubic foot per minute basis, and duct leaks are identified by inspection. [R#12]

In addition to this program, PG&E includes a "High Performance Ducts" component in its residential new construction program. Builders can earn incentives for installing and testing duct systems in accordance with requirements set forth by PG&E. [R#16]

Duke Power Company has implemented separate duct repair programs for new and existing homes. Duke became interested in the efforts at other utilities, particularly those in Florida, and decided to address duct leakage in its own service territory. Duke's programs are similar to those of other utilities. All contractors must receive training that is available through the North Carolina Alternative Energy Corporation.

The existing home program was piloted during 1992 in 150 homes in the Durham, N.C. area. The pilot encompassed both electric and gas-heated homes. In June of 1993, the program was expanded to the northern region of Duke's service territory and will be available to all Duke customers by the end of the year. This full-scale program is offered only to electric-heated homes, as the utility's evaluation of the pilot program found duct repair in gas-heated homes not to be cost-effective for the utility.

The duct repair program for new homes has been incorporated into Duke's residential new construction demand-side management program. A blower door analysis of the building is performed to validate air leakage of less than three percent in conditioned space. This program is available throughout the utility's service territory. [R#15] ■

This section focuses on the implementation strategies used in Florida Power Corporation's Duct Testing and Repair program and those planned for PG&E's system-wide duct repair and insulation program.

MARKETING AND DELIVERY

FLORIDA POWER CORPORATION

FPC's Duct Testing and Repair program is primarily marketed through its residential audit program. Because auditors essentially market the program to eligible customers, little additional advertising is necessary. That said, direct mail flyers and bill inserts specific to the duct testing program are used and the duct testing program is mentioned in some of the audit program marketing pieces.

During the residential energy audit the FPC auditor determines whether the customer's home or business will potentially benefit from a duct test. (Auditors must complete an auditor training in which they learn to identify candidates for duct repair.) If duct testing is applicable, details of the program are explained, and the customer is asked to sign a Duct Test Program form and a Customer Approval Form. Customers do not have to sign up at the time of the audit; if they wish, customers may contact FPC by telephone later to sign up for the program. In either case, the audit must be performed prior to participation and participation must be recommended by the auditor.

After the customer agrees to participate in the program, FPC assigns a contractor to the account and the contractor then calls the customer to arrange an appointment to perform the duct test. Through the duct test the contractor identifies the location of any leaks in the system and then prepares an estimate of the cost to repair the leaks.

The contractor also identifies carbon monoxide levels and draft sufficiency if combustion appliances are in the home. If carbon monoxide levels are above 400 parts per million, or if the appliance does not have sufficient draft, then the contractor will not perform the duct repair, unless the contractor determines that duct repair would correct the draft problem.

(Note that FSEC teaches 100 ppm of carbon monoxide as the level over which appliance service should be performed prior to any duct repair. While PG&E's program protocols for duct testing and repair have not been finalized, the training center currently teaches that a carbon monoxide level of 100 ppm or more indicates that appliance service is needed before weatherization can take place under the low income weatherization program. Under this program, once the appliance is serviced, weatherization may proceed as long as the carbon monoxide levels are lower than the American National Standards Institute standards, even if the standard exceeds 100 ppm for the particular appliance.)

After determining the viability and necessity for duct repairs, the contractor explains the recommendations and related customer cost. With the agreement of the customer, the contractor makes the necessary duct repairs at the same time as the duct test. Alternatively, the contractor may make an appointment to complete the repairs at a later date. Customers must pay their share of 50% of the duct repair cost directly to the contractor. ☞

After completion of the duct repair the contractor submits the appropriate paperwork to FPC and in about 10% of each contractor's jobs an FPC representative makes an appointment to inspect the repair work. After the repair work has been inspected by an FPC employee (or, if there is no inspection, approved), the contractor invoice is processed. If the repair work does not pass the inspection, the customer and contractor are informed, the contractor makes the necessary adjustments and the work is reinspected.[R#3]

PACIFIC GAS AND ELECTRIC

PG&E's program will be marketed solely to customers whose air conditioning demand is greater than 2,000 kWh. PG&E has discovered (and verified through end use metering studies) that residential customers' air conditioning use may be determined simply by subtracting the energy used during the month with the lowest bill from each summer month's usage. Although customers with air conditioning use less than 2,000 kWh will not be excluded from the program, PG&E will make an effort to convince them that the payback period for their portion of the cost to participate in the program would be too long to justify their participation.

The marketing effort will emphasize the potential savings and value of participating in the program. Targeted customers will receive a direct mail piece, which will be followed up with telemarketing. Based on the considerable interest in the pilot program, which was marketed solely with a somewhat ordinary direct mail piece, PG&E expects to have significant response to the system-wide program.

PG&E's contractor training process will be combined with the bidding process in a unique arrangement designed to address the fact that few contractors have enough experience with duct testing and repair on which to base a per-home bid. Contractors will first be selected, based on hourly rates and quality assurance protocols, to participate in a paid duct repair training. The training will start with a three day classroom session at PG&E's training center in Stockton. Then, contractors will spend three weeks in the field conducting duct tests and repairs on typical homes under the supervision of the instructors. Contractors will bill for the training on a time and materials basis. Then, after the training is completed, contractors will submit bids based on a flat charge per home. To start the program, PG&E anticipates selection of two or three contractors, but will depend on the results of the bidding process. After the program gets underway, PG&E will continue to offer training in order to ensure an adequate number of qualified individuals to implement the program.

PG&E's program will first be implemented in Fresno, (population 333,600) the site of the pilot program. Approximately 49,000 residential customers in Fresno have annual air conditioning use greater than 2,000 kWh. The 1993 program will also be implemented in Auburn, a town of population 9,800 located in the foot hills of the Sierra Nevada mountains. Auburn has no gas service and a significant use of heat pumps. Therefore, Auburn has

significant heating and air conditioning electricity use. PG&E hopes to reach about 200 or 300 homes in Auburn in 1993. In 1994, the program will be expanded to include customers in other parts of PG&E's service territory.[R#12]

MEASURES INSTALLED

Duct testing and repair programs typically include inspection of duct work and repair of ducts by certified contractors. Duct testing is done either with a blower door or a duct blaster, which use pressurization techniques to identify leaks in the duct system. Duct repairs are made with mastic and fiberglass mesh. FPC's program allows the use of duct tape meeting UL 101A specifications in the event that local codes or manufacturer's warranty prohibit the use of mastic.[R#3] However, FSEC does not recommend duct tape, unless the surface to which it will be adhered is perfectly clean, and the manufacturer of the ducts recommends duct tape. Duct testing and repair programs also typically include combustion safety testing. FSEC stresses the importance of combustion safety testing in its training sessions.

FPC's Duct Testing and Repair program pays for 50% of the cost of a duct test, up to $25 for the first HVAC unit, and $15 for each additional unit tested. FPC pays for 50% of the costs of duct repair, up to a maximum payment of $100.[R#3]

PG&E's program includes duct testing and repair, as well as insulation of duct work. Participants will be required to pay a portion of the cost for the testing, repair, and insulation, with PG&E covering the remainder of the cost. While the exact amount of the customer co-payment has not yet been decided, PG&E expects the customer payback to be about three years for the average customer.

STAFFING REQUIREMENTS

FPC's Duct Testing and Repair program, for example, is administered by the Program Manager, Jack Davis. Contractor training is provided through the Florida Solar Energy Center. (FPC also provided contractor training and certification prior to the establishment of the Florida Solar Energy Center Duct Doctoring program.) In 1993, 14 certified contractors were associated with the program. In addition, there are a number of FPC staff who are certified through the Florida Solar Energy Center (or FPC's earlier program) for duct testing and repair. These FPC staff conduct contractor inspections. FPC's 86 auditors cover the 32-county service area, promoting the Duct Testing and Repair program to eligible customers.[R#9]

PG&E's program will be administered by a program manager, Dave Laybourn. Contractor training will be provided through PG&E's training center. Historically, the training center was used solely for PG&E staff development, but recently the center has been utilized for contractor and trade ally trainings as well. The PG&E training has been developed based on work done by both FSEC and Proctor Engineering of California with input from a variety of other organizations.[R#13] ■

Monitoring and Evaluation

EVALUATION

In 1991, the Florida Solar Energy Center published the "Investigation on Air Distribution System Leakage and its Impacts in Central Florida Homes," for the Florida Governor's Office.[R#6] The study was conducted in 1989 by researchers from the Florida Solar Energy Center and Natural Florida Retrofit: James B. Cummings, John J. Tooley Jr., and Neil Moyer. This report documented the results of duct tests made in a random sample of 160 Florida homes. Homes were selected from each of five groups, depending on the location of the air handler – attic, closet, garage, outside package units (on site-built homes only), and HUD-code mobile homes.

Blower door tests were done on 100 homes and duct repairs were then completed on 50 of those homes. The report found weather-normalized energy and peak demand savings attributable to duct repair with an average reduction in cooling energy use of 17.4%.[R#6] (Savings were about 7 kWh/day, and average cooling energy use after duct repair was 33.6 kWh/day.) The study reported an estimated 1,400 kWh per year energy savings in 46 homes where ducts were repaired.[R#6] The report asserted that typical winter peak demand savings of 1.6 kW per home could be expected.[R#6,11]

The study found some of the most common reasons for duct leakage, both in supply ducts (which supply air to the home) and return ducts (through which air is returned to the air handler). Leakage problems differed depending upon the location of the air handlers and whether the home was site-built or was a HUD-code mobile home.

Homes with air handlers in the attic experienced the lowest reduction in cooling energy use, at 14.7%. However, energy use in homes where the air handler was located in the attic used significantly more cooling energy than any of the other types of homes included in the study. After duct repair, homes with air handlers in the attic used 42.6 kWh/day for cooling, compared to 28.3 kWh/day for garage air handlers, 30.6 kWh/day for mobile homes, 31.9 kWh/day for package air handlers, and 37.1 kWh/day for closet air handlers.[R#6]

Homes with the air handler in the garage had the lowest before and after-repair energy use, with average reduction in cooling energy use of 17.3%. Package units located outside the home had the highest average cooling energy use reduction, at 18.6%. Homes with air handlers in the closet had average reductions of 15.9%, and HUD-code mobile homes had average reduction of 15.7%.[R#6]

Air Handler Location	*Number of Homes Tested*	*Cooling Energy Use Before Duct Repair (kWh/day)*	*Cooling Energy Use After Duct Repair (kWh/day)*	*% Reduction*
Attic	8	49.9	42.6	14.7
Closet	10	44.1	37.1	15.9
Garage	9	34.1	28.3	17.3
Package	9	39.2	31.9	18.6
Mobile Homes	10	36.2	30.6	15.7
Total / Average	46	40.6	33.6	17.2

[R#6]

In site-built homes, the most common source of return leaks was in the return plenum (a return plenum is "an enclosed space where air is collected before being drawn into the air handler").[R#5] Typically, the return plenum serves as the support shelf for the air handler, and may not be air tight. The return plenum may be framed into the walls of the air handler room, and the walls may not be air tight either. Other sources of return leaks in site-built homes include: poorly sealed return register connections; leaky air handler cabinets; disconnections between return ducts and other ducts, registers, or plenums; or poorly sealed chase lines (chase lines carry coolant or condensate from outdoors to the air handler through the concrete slab; they may be depressurized, causing infiltration of radon and other soil gases).[R#6]

Supply leaks in site-built homes are most often found at the connection of the supply plenum to the air handler or furnace cabinet. Other sources of supply leaks in site-built homes include: leaky connections between the supply duct and the supply register; leaky flex duct connections, often where the flex duct joins to duct board; and supply duct leaks due to holes or photodegradation. [R#6]

Most HUD-code mobile homes have package air handlers. Leaks in the package unit cabinet are the most common cause of return leaks in these types of homes. Typically, HUD-code mobile homes have return ducts that meet the house floor where there is a return plenum box which may leak to adjacent floors at the floor connection. Like site-built homes, flex duct connections may be leaky. Homes where the subfloor space is used as a return plenum may experience significant leakage, as the subfloor space typically is not air tight.

Supply leaks in HUD-code mobile homes are typically larger than return leaks. They are most commonly found at poorly sealed supply arm joints between the main supply trunk and the metal shafts to the floor. Sources of large supply leaks in HUD-code mobile homes may include leaks to floor connections without good air tight seals, leaks at the end of supply trunk lines which have not been sealed, misaligned supply registers, and leaks in the flex duct connecting the air handler to the main supply trunk line.[R#6]

Summer demand reductions were not calculated as part of the 160 home study, because demand reduction is related to air conditioner oversizing. The study had no way of knowing air conditioner capacity or cooling load, so demand reduction could not be reliably estimated without time of day monitoring.[R#11]

In 1991, a study of several homes in Arkansas was conducted by Home Comfort, funded by the Arkansas Energy Office. Duct repairs were made in 19 homes in the Fayetteville/Springdale area and Little Rock. Five of the homes had two air handlers, for a total of 24 air handling systems, five electric and 19 gas. Nine air handlers were located in attics, five in crawlspaces, four in garages, five in interior closets, and one was an outdoor package unit. The homes ranged in age from less than one year to 35 years.[R#2]

In the Arkansas study, an average 21.8% reduction in winter heating energy consumption was attained. On average, leakage was reduced by 446 cubic feet per minute at 50 pascals. For the homes with electric air handling systems, the actual reduction in monthly energy use (at 41°F average outdoor temperature), was 273 kWh for the home with one air handler, 921 kWh for one of the homes with two air handlers, and 291 kWh for the other home with two electric air handlers. The average monthly savings were 495 kWh, or 1,980 kWh per year, assuming a four month heating season.[R#2] ■

Program Savings

This section focuses on the savings achieved by FPC's Duct Testing and Repair program as an illustration of a utility's initial impacts with this type of efficiency program.

Accurate calculation of estimated savings for utility programs, in the absence of metered results, must take two important factors into account. First, annual and regional variations in climate must be considered. Weather patterns will affect heating and cooling energy use, and the savings that are achieved due to duct repair will fluctuate accordingly. Second, the effectiveness of the testing and repair must be evaluated. This latter factor is likely to be directly influenced by the efficacy of the contractor training process.

In its 1990 filing FPC estimated annual energy reductions due to the program at 1,000 kWh per participant.[R#10] *The Results Center* used this figure to determine annual, cumulative, and lifecycle energy savings for the program as shown in the FPC Program Savings Overview Table. In addition, the annual energy savings figure is used to calculate FPC's cost of saved energy in the Cost of the Program section. FPC estimates winter peak demand savings attributable to the Duct Testing and Repair program at 1.02 kW per customer; summer peak demand savings are estimated at 0.5 kW. FPC's estimates are conservative in comparison to the Florida Solar Energy Center figures for typical winter peak demand savings of 1.6 kW per home, and typical energy savings of 1,400 kWh per year. (PG&E anticipates that energy savings will be about 20% of the cooling energy use.)

With a total of 8,895 duct repairs between 1991 and 1992, total annual energy savings for FPC's program are 8.9 GWh, total winter peak demand reduction is 9.1 MW, and summer peak demand reduction is 4.4 MW.

PARTICIPATION RATES

Most of the utilities' duct testing programs currently being implemented are targeted at residential customers. FPC's program is limited to those who reside in single or multi-family homes that have accessible duct systems. However, multi-family units where one unit is on top of another unit may not be tested or repaired, due to health and safety concerns.[R#3] PG&E is planning to target only those customers whose air conditioning demand exceeds 2,000 kWh. This limitation is proposed for two reasons: the pilot study showed that higher consumption groups had higher percentage savings, and the payback period for the customer contribution for the duct repair will be acceptable (three years or less) for customers who have air conditioning demand greater than 2,000 kWh.

Accessibility of ducts is an important consideration. In the 1991 Florida Solar Energy Center study of 160

FPC Program Participation Table	*Duct Repairs Completed*	*Annual Energy Savings per Participant (kWh)*	*Annual Winter Demand Savings per Participant (kW)*
1991	1,801	1,000	1.0
1992	7,094	1,000	1.0
Total	8,895		

FPC Program Savings Overview Table	*Annual Energy Savings (MWh)*	*Cumulative Energy Savings (MWh)*	*Lifecycle Energy Savings (MWh)*	*Annual Winter Peak Demand Savings (MW)*	*Cumulative Winter Peak Demand Savings (MW)*	*Annual Summer Peak Demand Savings (MW)*	*Cumulative Summer Peak Demand Savings (MW)*
1991	1,801	1,801	90,050	1.84	1.84	0.90	0.90
1992	7,094	8,895	354,700	7.26	9.10	3.55	4.45
Total	8,895	10,696	444,750	9.10		4.45	

homes, a number of homes, mostly new HUD-code mobile homes where supply ducts were located in the ceilings, were not included in the duct repair sample due to inaccessibility of the ducts.[R#6]

In its 1990 filing to the Florida Public Service Commission, FPC estimated the number of customers eligible to participate in the Duct Testing program at one million, virtually all of its residential customers.[R#10] During the first year of the program in 1991, 1,801 customers received duct repairs through the program. Participation in 1992 increased dramatically, with 9,690 customers receiving duct tests, and repairs being completed in 7,094 customers' homes. The ratio of repairs to tests in 1992 was thus 0.73 to 1. Through 1992, total participation in the program has been 8,895, or slightly less than 1%.[R#9]

FREE RIDERSHIP

Free-ridership is not likely to be an issue for any duct testing and repair programs currently being implemented. Duct testing and repair is not yet a commonly performed or recommended practice.

Although FPC's savings figures were not adjusted for free-riders or other factors that may affect actual program savings, the use of a conservative per-customer savings estimate effectively derates the savings figures presented for the program, though it is unclear whether this was the intent in using such conservative numbers.

MEASURE LIFETIME

Because mastic and fiberglass mesh are typically used on duct repairs, the measure lifetime is essentially the same as the lifetime of the duct system. Duct system lifetime is typically the same as the lifetime of the home, which can range from 40 to 70 or more years depending on the home, its age at the time of repair, and its construction. Where duct tape is used, FPC only permits tape meeting UL 181A specifications. For the purposes of calculating lifecycle savings and cost of saved energy, *The Results Center* used 50 years as the average measure lifetime. ■

Cost of the Program

This section focuses on the costs of FPC's Duct Testing and Repair Program.

In 1992, FPC spent a total of $1.0 million on the Duct Testing and Repair program. Program expenditures from 1991 were not available.

For the 1991 investigation of 19 Arkansas homes, the average cost of materials to repair duct systems was $39.95, not including blower door testing or labor costs. Based on the expenditures in Arkansas, the study estimated that a reasonable charge for testing and repair of duct systems might average $500 per home.

COST EFFECTIVENESS

The Results Center determined the cost per kW saved for the Duct Testing and Repair program, based on a simple calculation of total 1992 costs divided by 1992 winter peak demand savings. The resulting cost is $141/kW.

Based on the annual energy savings estimation as described in the Program Savings section, and the 1992 utility costs, *The Results Center* calculated the cost of saved energy for the program. The cost of saved energy ranges from 2.21 ¢/kWh to 5.18 ¢/kWh, depending on the discount rate used. At a 5% real discount rate the cost of saved energy for the program in 1992 was 3.11¢/kWh.

COST PER PARTICIPANT

The Results Center calculated FPC's total utility cost per participant for 1992 at $115.

COST COMPONENTS

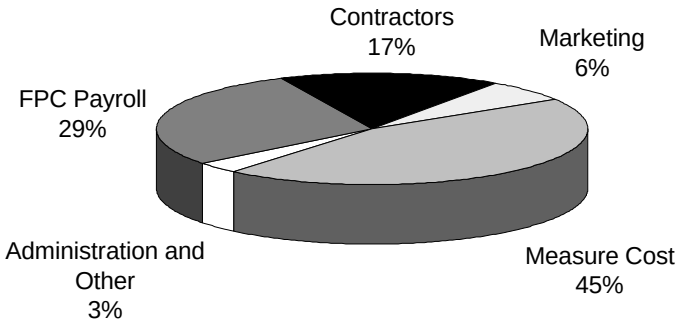
Measure costs made up the largest portion of FPC's program expenditures in 1992, at 44.7% of the total expenditure. Measure costs were comprised of incentive payments, at 43.2% of the total cost, materials and supplies, at 1.2%, and 0.3% for blower doors. To start the program, ten blower doors were purchased at $1,625 each, and the cost to purchase these blower doors has been amortized over the anticipated life of the program.

FPC Program Cost of Saved Energy Table (¢/kWh)	*Discount Rates*						
	3%	4%	5%	6%	7%	8%	9%
1992	2.21	2.64	3.11	3.60	4.11	4.64	5.18

FPC Program Costs Overview Table	*Administration and Other (x1000)*	*FPC Payroll (x1000)*	*Contractors (x1000)*	*Marketing (x1000)*	*Measure Cost (x1000)*	*Total Program Cost (x1000)*	*Cost per Participant*
1992	$35.2	$294.1	$170.1	$65.7	$457.3	$1,022.3	$114.93

FPC payroll costs make up the next significant portion of program expenditures, at 28.8%. Contractor payments were an additional 16.6%, and marketing was 6.4% of the total 1992 cost. Because the program is marketed primarily through FPC's residential energy audit program, much of the marketing costs for the Duct Testing and Repair program are contained in the budget for the Energy Audit program. The actual marketing cost for the Duct Testing and Repair program may be higher than the figure reflected here.

Administrative costs make up the remainder of the cost components, at 3.4%. For this program, administrative costs include vehicle expenses at 2.5%, and miscellaneous costs, at 0.9%.[R#9] ■



LESSONS LEARNED

In 1991, FPC's Duct Testing and Repair program became the first major U.S. utility effort that addressed duct leakage on a system-wide basis. Florida Power & Light's program began shortly after FPC's program was initiated, PG&E's pilot program was nearing completion in 1991, and Duke's program was piloted in 1992. These programs have been widely accepted by customers and have produced significant cost effective energy and capacity savings. With typical savings of 1,400 kWh per home per year, customers have significant incentive to participate in these programs.

Proper training is essential to the accurate identification of duct leaks and their safe repair. Because duct testing and repair is a relatively new technique, training is vital to ensure that contractors are knowledgeable and efficient in their implementation of the program. Additionally, a program's positive reputation is dependent upon the diligence of contractors and inspectors in adhering to the testing and repair standards set forth in their training. FPC's partnership with the Florida Solar Energy Center to provide training for contractors who inspect and repair ducts for the program has been vital to the program's success. PG&E consulted FSEC to identify the training needs for their program and will make use of its existing training center to provide contractor training for the program.

Duct testing and repair is a developing field and as such national standards do not exist. The Florida Solar Energy Center Duct Doctoring manual makes informed recommendations regarding acceptable materials, procedures, and practices. However development of national standards would certainly help insure that duct testing and repairs occur in accordance with safe practices. Proper training of auditors and duct inspectors can reduce the instances of unproductive visits and insure that repairs are not made until safety concerns are addressed.

Similarly, standards that ensure proper duct installation in the first place should be adopted, as they have been in Florida. Florida's code is based on the Southern Building Code Congress International, Inc. building code, which requires access to attics so that mechanical systems located above the ceiling may be easily serviced.

By using the utility's existing energy audit program as the primary marketing tool for the program, FPC has avoided significant additional marketing costs while at the same time ensuring that only appropriate prospective customers become involved with the program. In 1992, the ratio of repairs to tests was 0.7 to 1. Reasons for not performing a repair after the test can range from determination that repair is unnecessary to identification of potential combustion safety problems which are not mitigated, thus precluding repair, to unwillingness of the consumer to proceed with repairs.

A duct testing and repair program may have an added educational benefit in regard to safety practices for combustion equipment. While most consumers know basic safety measures to protect against electric shock and other hazards posed by the presence of electricity in the home, few are aware of safety practices applicable to combustion appliances. In FPC's program, if combustion safety prob-

lems such as high carbon monoxide levels or down drafting in vent pipes are identified, then the customer is presented with a caution letter suggesting that the customer contact the local gas company for inspection and repair.

The Arkansas study reported that combustion safety problems were discovered in the majority of the gas heated homes included in the investigation. Some of the combustion safety problems were minor, such as vent pipes being slightly shorter than the code specification. However, some major problems such as pressure differentials causing spillage of flue gases, pipe corrosion, and gas line leaks were also discovered in some homes. In most cases, the combustion safety problems were addressed prior to sealing the duct systems.[R#2]

Current research has not yet addressed the specific environmental benefits of duct repair. However, it seems apparent that reductions in cooling energy use would result in concurrent reductions in chlorofluorocarbons and hydrochlorofluorocarbons that are used in cooling applications.

TRANSFERABILITY

Given the importance of proper training to the success of such a program, the transferability of a duct testing and repair program is contingent on the availability of training and the willingness of utility personnel to travel in order to be appropriately qualified. The Florida Solar Energy Center's six-day Duct Doctoring course is one such comprehensive training opportunity; similarly, PG&E's use of its training center as a forum through which to provide contractor training has made possible the implementation of their duct testing program.

With qualified personnel, a duct testing and repair program could be a stand alone program, or could easily be incorporated into any existing residential weatherization or retrofit program. These programs are not limited to cooling-dominated climates. Homes with forced air heating are also likely to achieve significant energy savings with duct repair, as demonstrated by the 1991 Arkansas study, and as PG&E anticipates will occur with its program in Auburn. In Florida, where electric resistance heat typically serves as a backup to central heat pump systems, the potential for winter peak demand savings is even greater than the summer peak demand impacts.[R#6]

In 1993, the Florida Solar Energy Center embarked on a two-year study, funded by the Florida Energy Office, of uncontrolled air flow (including exhaust systems, ventilation systems, return design problems, duct leakage, and repair) in non-residential buildings. Jim Cummings, Senior Research Analyst at the Center, believes that not only are energy and capacity savings likely to be significant in commercial buildings, the negative impacts of duct leakage, such as moisture damage and air quality concerns, may well be more pronounced in non-residential facilities. Thus, it is likely that there will be significant impetus for non-residential customers to participate in a duct repair program. The potential for success of a duct testing and repair program is not limited to the residential sector, but extends to commercial, industrial, and institutional customers as well. ■

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