Measured Energy Savings of a Comprehensive Retrofit in an Existing Florida Residence

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ABSTRACT

Simulation analysis suggests that electricity consumption can be reduced up to 40% in existing Florida homes. To test this theory, an all-electric home was located in Miami, Florida upon which to perform a variety of retrofits. The total annual electricity consumption in the one year base-line period preceding the study was 20,733 kWh. Detailed instrumentation and metering equipment was installed in May of 1995 so that each energy end-use could be evaluated. A year of baseline monitoring was followed by installation of a battery of retrofits: radiant barrier with additional attic ventilation, a SEER 15 air conditioner, an add-on solar water heating system, a super efficient refrigerator, a smaller, more efficient pool pump and compact fluorescent lighting.

The results showed a 40-45% reduction in measured daily energy use (28.6 kWh/day). Annual savings were between 8,000 and 10,300 kWh depending on the base year of reference. Space cooling was reduced by 42% and water heating by more than 70%.

Introduction

Annual residential energy usage in detached single family South Florida homes averages 15,192 kWh per household (SRC, 1992). One study, examining the potential savings in existing housing in the region estimated by building energy simulations that consumption could be reduced by 39% (Parker et al., 1992). A field study conducted by Messenger et al. (1982) examined the performance of a variety of residential retrofits applied to 25 homes in Palm Beach. Improvements included insulation, duct repair, new refrigerators and solar water heaters. Average residential electricity use was 24,660 kWh with measured total electricity savings amounting to 27% of pre-retrofit consumption. Although successful, the project installed a variety of measures rather than an aggressive attempt to obtain the maximum savings available. Further, the study developed no information on the timing of the savings – an important issue to Florida utilities.

The objective of our study was to: 1) perform a comprehensive retrofit of envelope, air conditioning, refrigeration, lighting, and pool pumping systems in a Florida home using available technologies, measuring energy use before and after retrofit, and 2) determine the time-of-day demand reduction profiles for the savings of each measure.

Test Site Description

The home selected for the pilot study was conventional a three-bedroom single family home 20 miles north of Miami, Florida. The single story structure was built in 1984 and contains approximately 1,500 square feet of gross floor area and 1,243 ft^2 of conditioned floor area. The site was selected for the study based on a previous history of high utility costs.

The home has an uninsulated slab on grade foundation with 8" concrete block construction and R-5 interior insulation on the walls. The ceiling is covered by R-19 blown insulation which is unevenly distributed (average depth is ~6 inches, but varies from 4 -12"). The attic space has a black asphalt shingle roof with small irregularly spaced soffits, but no ridge vents. The living room has a cathedral ceiling. Infrared thermography revealed evidence of missing knee wall insulation as well as compressed batt insulation over the cathedralized sections of the attic.

The home is occupied by two working adults and a pet dog. On weekdays, both husband and wife depart the home for work at approximately 7 AM arriving home at approximately 6 PM. Both are typically home weekends. A programmable thermostat controls the heating and cooling system. The programmable thermostat sets up the interior temperature to 85°F during week day daytime hours between 8 AM and 4 PM; 83°F at 4 PM and 80°F beginning at 5:30 PM. The thermostat is also set to 80°F during weekends. The occupants generally ventilate rather than use the air conditioner during the months of November - March. Located in South Florida, the homeowners reported little use of the central heating system.

Monitoring

In April of 1995, site was instrumented with a multichannel data logger to both measure total electrical load as well as each of the major end-use loads:

- Total electricity
- Hot water
- Range
- Washer
- Air conditioner and air handler
- Refrigerator
- Dryer
- Pool pump

A weather tower was installed to obtain data on ambient air temperature, relative humidity and solar irradiance. We used long periods of pre and post retrofit data for each end use to determine the impact of individual measures. Changes in miscellaneous loads, including lighting and ceiling fan use, were tracked by subtracting the major electrical end uses from total.

Based on collected data over the first half year of monitoring, it was possible to characterize the magnitude of the various end-use loads as summarized in Figure 1. Cooling energy end-use was 40% of annual consumption followed by refrigeration, dryer and hot water end-uses. "Other" consists of lighting and miscellaneous energy consumption.

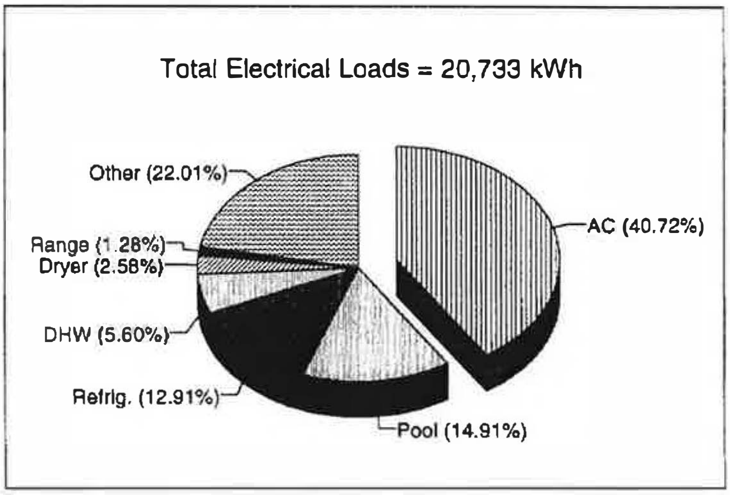

Figure 1. Total annual electrical end-uses.

Attic Radiant Barrier

Improving attic thermal performance is of fundamental to controlling residential cooling loads in hot climates. Accumulating research data shows that the influence of attics on space cooling demand is not only due to the change in ceiling heat flux, but often due to attic influence on heat gain to duct systems and on air infiltration into the building. The importance of ceiling heat flux has long been recognized, with insulation a very effective method of controlling excessive gain. However, when ducts are present in the attic, the magnitude of heat gain to the thermal distribution system under peak conditions can be greater than the ceiling heat flux in well-insulated attics (Parker et al., 1993; Hageman and Modera, 1996).[1] Such heat gains can be reduced in new residential housing though the use of white reflective roofing (Parker and Barkaszi, 1997). However, with the test home's black asphalt shingle roof, the options are more limited. Previous test data has shown that black asphalt shingles absorb approximately 97% of incident solar radiation. The attic floor has R-19 blown insulation although unevenly distributed. Research at FSEC had demonstrated the effectiveness of radiant barrier systems (RBS) in controlling attic cooling loads with conventional roofing (Fairey et al., 1988).

On July 24, 1995, during the first summer of the monitoring, we retrofitted an RBS under the attic roof decking to reduce heat gain. Average maximum daily summer attic air temperatures were reduced by about 20 degrees (Figure 2). Using days with matched meteorological conditions before and after the retrofit (Figure 3) we were able to show that peak day summer air conditioning savings were approximately 14%. Table 1 shows weekday and weekend days pre and post retrofit with sunny, but similar temperature and solar conditions.

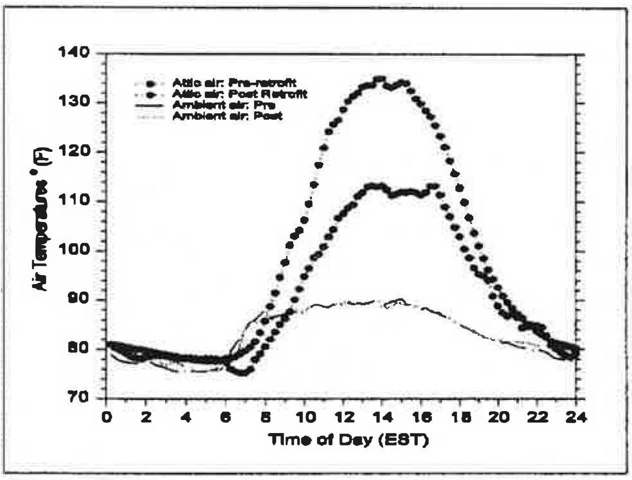

Figure 2. Two matching pre and post days showing ambient air temperatures and attic air temperature before and after the installation of a radiant barrier.

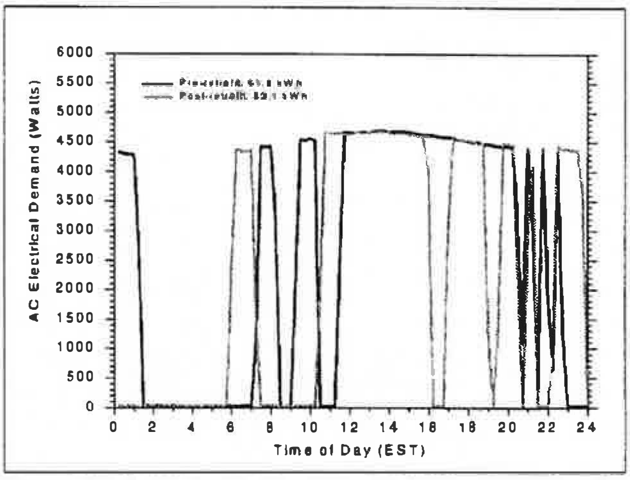

Figure 3. Comparative cooling system performance on same two weekend days with and without radiant barrier.

The AC reduction on the hottest days in which the home is occupied (no daytime thermostat set up) was 10-15%. Savings were considerably lower on cloudy or cooler days and week day periods when the AC is run less frequently during daytime hours. Using long-term periods in the summer of 1995, before and after the installation in the radiant barrier we estimated annual air conditioning energy use was reduced by about 5.5% (~430 kWh) from the installation.[2] This magnitude is consistent with other whole house monitoring of the impact of radiant barrier systems which found cooling energy savings of 7-10 percent

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[1] A simple calculation illustrates this fact. The study house has a 1,500 square foot ceiling with R-19 attic insulation. Supply ducts typically comprise a combined area of ~25% of the gross floor area (see Gu et al., 1997; Jump and Modera, 1994). With the peak attic temperatures measured at 135°F, and 80°F maintained inside, a UA ΔT calculation shows a ceiling heat gain of 4,300 Btu/hr. With R-4 ducts in the attic and a 57°F air conditioner supply temperature, the heat gain to the duct system is 7,300 Btu/hr if the cooling system ran the full hour under design conditions – nearly twice the ceiling flux.

[2] Regression results for daily AC energy were as follows from data for the summer of 1995. Average ΔT from June - September was 1.68°F:

Pre RBS: AC kWh = 42.136 + 5.480 (ΔT) r^2 = 0.82
Post RBS: AC kWh = 40.915 + 4.923 (ΔT) r^2 = 0.82

Table 1. Matched Days Comparison for RBS Retrofit for Peak Summer Days, 1995

Period	Date (Julian)	Avg. Amb. Temp. (°F)	Maximum Attic Temp.	AC kWh
Weekday				
Pre-RBS	May 18th (138)	84.3°F	138.0°F	54.1
Post RBS	Aug. 8th (220)	84.3°F	123.0°F	49.2
Reduction			*15.0 °F*	*5.9 kWh (11%)*
Weekend				
Pre-RBS	June 13th (161)	83.1°F	135.0°F	61.6
Post RBS	Aug 7th (219)	83.4°F	113.3°F	53.1
Reduction			*21.7 °F*	*8.5 kWh (14%)*

(Fairey et al., 1988). However, the cost of the retrofit installation was $1,100, as compared with the $400 that might be typical with new construction. With an estimated $32 annual savings, payback appears only reasonable for new construction or owner installed applications.

Replacement of the Air Conditioning System

The greatest energy user at the study home was the eight-year old air conditioning (AC) system. The system was a conventional, 3.5-ton split system *(York H2CCO42A06A)*. The air handler was installed in the garage. The system has a nominal seasonal energy efficiency ratio (SEER) of 9.0 Btu/W at rated conditions. The extensive duct system consisted of R-4 flex duct and is located in the attic.

Average consumption during the air conditioning season (273 days of the year) averaged 28.8 kWh/day: (7,750 kWh/yr). Even though a programmable thermostat only energizes the system when the occupants are home (evenings and weekends) with an 80° set point, consumption was still quite high and the AC frequently operated without cycling.

The duct system was suspected, but pressure tests revealed that is was relatively tight (sealed as part of the utilities duct program). We used two *Duct Blaster* testing devices to determine the relative leakage in the return and supply sides of the duct system. Total tested leakage of the duct system to outside the conditioned space at a 25 Pa reference pressure was 63 cfm. Given its 1,240 square feet of conditioned area, the outside duct leakage 0.044 cfm/ft^2. This compares to the 0.03 cfm/ft^2 proposed as a standard for utility new homes programs. In summary, we found that the duct system of the house was well sealed and not the source of the poor cooling performance. We also used the blower door to measure house tightness. The total overall building tightness at a 50 Pa pressure showed a leakage rate of 1,632 cfm or 7.9 ACH with a house ELA of 84.5 square inches. The results indicate a fairly tight building envelope.

Audit of the AC air handler revealed the cause for the poor cooling performance. The indoor 3.5-ton air coil had a rated air flow requirement of 1,400 cfm. However, measuring with a flow hood, we discovered the return air flow was only about 550 cfm - 40% of the recommended level. The reason was a long thirty foot length of 14- inch return flex duct which greatly increased the static pressure drop on the return side of the fan coil. The return duct was both too long and too small in diameter to accommodate the required air flow for proper system operation. We performed a test of the AC efficiency at an 83°F outdoor temperature - a typical condition since the average temperature in August is 81°F.

Test data were taken before and after the AC coil:

T_{supply} = 52.7° RH_{supply} = 86%
T_{return} = 79.5° RH_{return} = 58%
Q_{return} = 550cfm

The sensible cooling was then:

$$550 \times 60 \times (79.5 - 52.7) \times 0.018 = 15{,}920 \text{ Btu/hr}$$

Total cooling considers the enthalpy of the return and supply air (33 and 21 Btu/lb, respectively). There is 13.25 cubic feet of dry air per pound of dry air at the mean temperature.

$$Q_{tot} = (550/13.25) \times 60 \times (33 - 21) = 29{,}887 \text{ Btu}$$

This equates to an EER of approximately 6.3 Btu/W at an 83°F outdoor temperature. Except for the high return air temperatures, the coil would likely ice up. Other field research showed that low evaporator coil air flow is both pervasive in Florida, and responsible for a significant decrease in cooling performance in both new and existing homes (Parker et al., 1997).

We also performed a Manual J calculation on the loads for the home which indicated an air conditioner size of 1.93 tons. Based on the results, we chose a 26,400 Btu/hr single speed outdoor unit *(Trane TTY024A)* was matched with a high efficiency variable speed indoor fan coil unit (*TWE040E13*). The fan speed varies with the cooling load, but uses a speed control profile which enhances coil humidity removal. The existing duct sizes (14" flex) were inadequate for the needed air flow so a completely new plenum box and a short return duct section was fabricated, sealed and tested.

The new AC system with a rated SEER of 15.0 Btu/W, was installed on May 31, 1996 with final correction of indoor unit speed settings complete by June 4th. On August 12th, 1996 a test evaluated the new machine performance as was done with the pre-retrofit system. The data were taken on a hot summer day with a measured inlet air temperature to the condenser of 96.2°F. Both a flow hood and resistance heat tests showed a fan flow of 1,020 cfm at high speed with a fan power draw of only 252 W.[3] Total air handler and compressor power draw at 2,419 W. A temperature difference of 20.2°F was measured across the coil with 680 ml of condensate measured over a ten minute period as a check on the measured enthalpy conditions. Measured sensible cooling was 22,230 Btu/hr; measured latent cooling was 9,550 Btu/hr for a sensible heat ratio (SHR) of 0.70. Total cooling capacity was 31,780 Btu for an EER of 13.1 Btu/W. Thus, the audit test revealed the relative space cooling efficiency was increased by over 50% by the replacement unit.

Using a year of data post installation from June 5th, 1996 - June 4th, 1997, the air conditioning consumption was reduced to 4,453 kWh for a 42% reduction in cooling energy use. Average weather conditions (temperature and solar irradiance) were very similar in the two years. Figure 4 shows the measured air conditioner energy consumption over the period. Figure 5 shows the average daily profile of the energy savings.

[3] This compares to 26% greater fan power for the pre-retrofit air handler (319 W) to produce half as much air flow as the replacement unit.

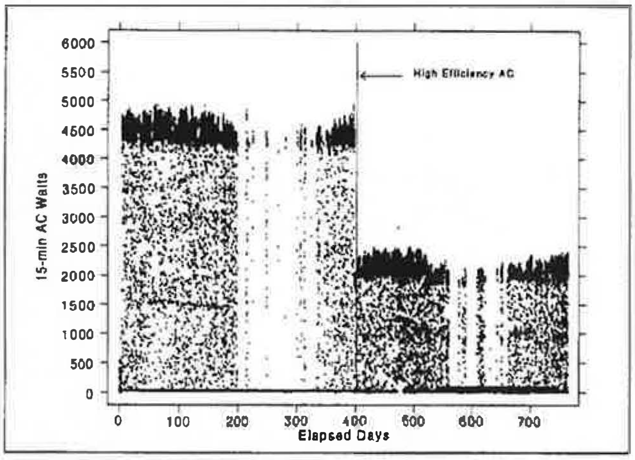


Figure 4. AC consumption before and after system replacement. Infrequent AC use during the mild South Florida winters are clearly visible each year.

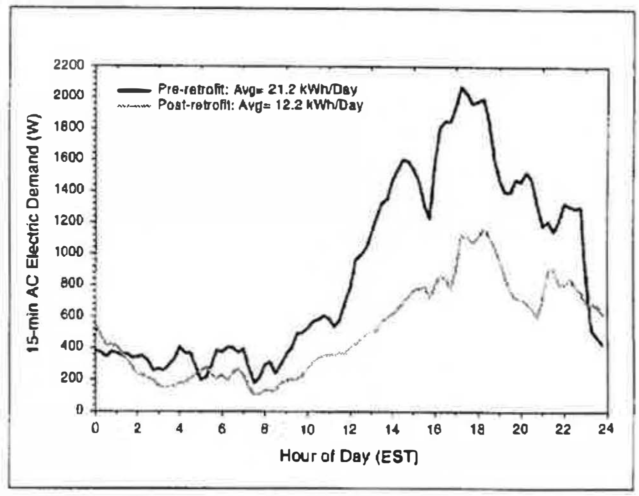


Figure 5. Average daily profile of cooling energy use in years pre and post retrofit.

We did experience some "take-back" after the installation. This was specifically mentioned by the homeowners; once the improved system was installed they chose to lower the nighttime temperatures to improve comfort. However, Figures 6 and 7 show a comparison of the daily air conditioning energy use at the home plotted against the measured temperature difference between the inside and ambient over year long periods. Both periods show the expected behavior; air conditioning rises with increasing temperature difference between the interior and exterior. The AC use in the baseline home increases by 12.2% for each degree change in the daily temperature difference. However, the slope of the regression line between the two systems (4.89 kWh/°F vs. 2.25 kWh/°F) shows that the improved AC system reduced cooling system electricity consumption by 64% at equivalent loads.

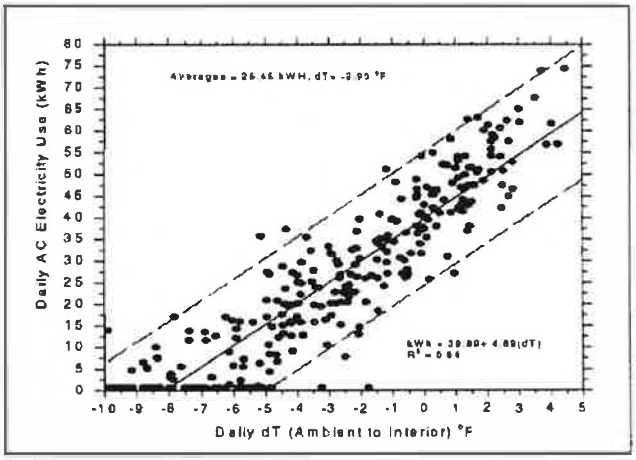


Figure 6. Regression plot of daily AC energy use in year prior to retrofit.

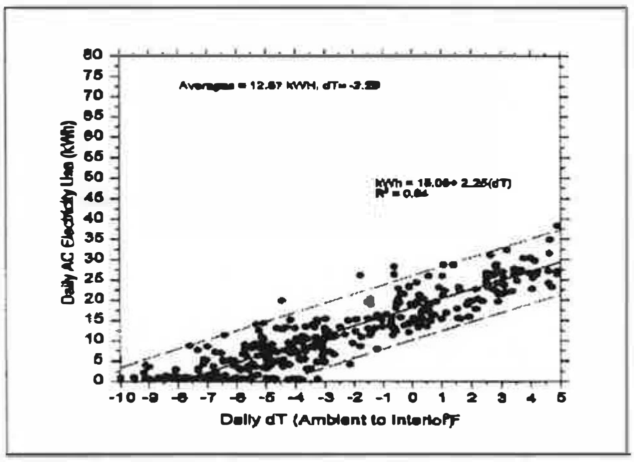


Figure 7. Regression plot of daily AC energy use in year post retrofit.

With measured annual savings of 3,259 kWh ($277/yr) against a cost of $4,071 (the high cost reflects the premium priced AC as well as numerous modifications to enhance coil air flow) the retrofit has a simple pay back of 15 years. This is long, but the existing unit was near the end of its useful life. Since replacing the existing unit with a standard efficiency one would cost approximately $2,000 the payback under this scenario looks much more attractive (<10 years). Also, the new variable speed air handler unit measurably reduced operating sound levels and improved interior comfort levels by reducing interior humidity. Finally, the savings would have been even greater in a household occupied during the daytime hours.

Solar Hot Water System

The study home had a conventional electric resistance storage water heater (*Ruud Pacemaker PE-40-2*) with two 4,500 W elements located in the garage. The measured hot water temperature from the tap was 117°F; the tank is set to 130°F at its thermostat. We monitored both water heater electricity use as well as hot water consumption (gallons each 15-minutes) from May 1995 - February 15, 1996 when a small solar water heating system was added.

Measured hot water consumption averaged 30 gallons per day - considerably less than the "typical" DOE standard profile of 64 gallons per day. This is at least partially due to the small household size - two adults without children. Measured hot water electricity consumption averaged 3.7 kWh per day prior to installation of the solar system (1,350 kWh/yr) and closely tracked measured daily hot water consumption (Figure 8). The remaining variation in energy use shown in the scatter plot is primarily due to seasonal differences in inlet tap water temperature to the tank.

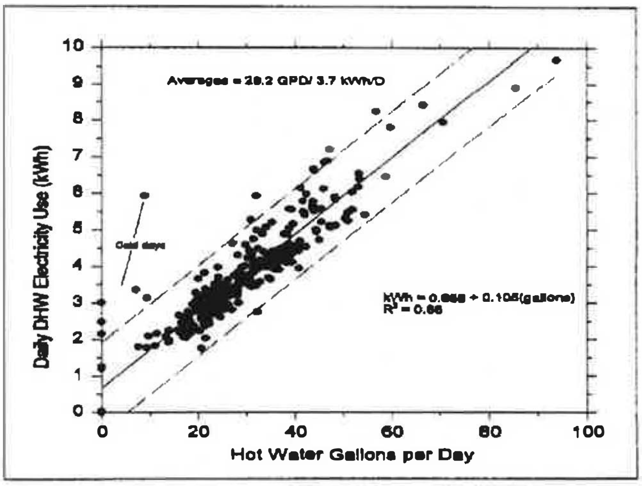


Figure 8. Regression of daily water heater energy use against gallons consumed in 1995.

Solar water heating systems are a demonstrated technology to significantly reduce water heating energy use in Florida (Merrigan, 1983). The solar hot water heater chosen for the project is an add-on type, so called because it is added onto the existing 52-gallon hot water tank. Manufactured by *Solar Development Inc.*, the system won the 1991 Florida Governor's competition for a low-cost solar water heating system. To lower costs, the collector is only 20 square feet (2 x 10' flat plate collector) and the unit has no parasitic energy consumption since a small solar electric photovoltaic panel powers its DC pump.

Since installation on February 16, 1996, back-up water heating electricity averaged 1.09 kWh/day or a savings of 72% in spite of a slight increase in hot water consumption. The change in 15-minute water heating electricity demand is shown in Figure 9. The daily hot water electricity demand profile before and after retrofit is shown in Figure 10 (top of the next page). Measured annual energy savings using a year pre and post installation was 951 kWh/yr, with a value of approximately $81 at current energy prices. The solar water heater was installed for $1,650 so that the simple payback is long - 20 years. However, do-it-yourself persons could easily install a kit version of the system for about a $1,000.

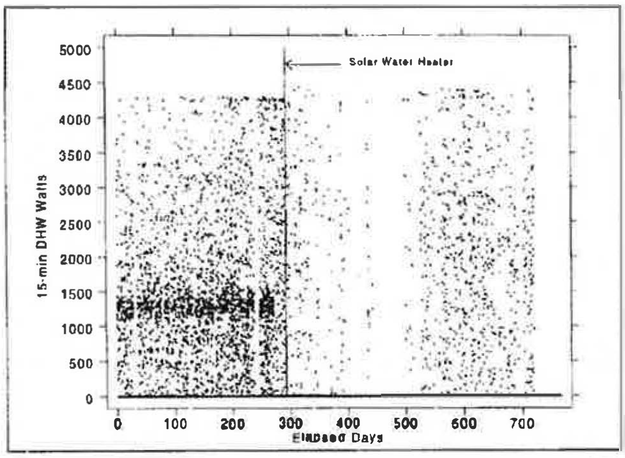


Figure 9. Time series plot of water heater energy use before and after solar system installation.

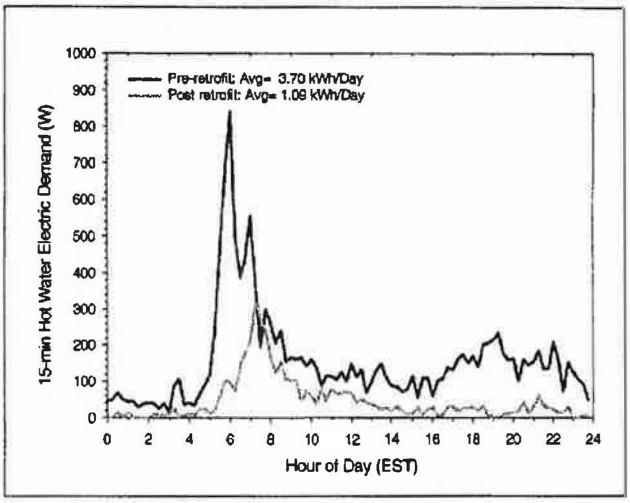


Figure 10. Daily water heater energy demand profile in the years pre and post solar retrofit.

Pool Pump Replacement

Like 22% of Florida homes, the study site has an unheated 15,000 gallon pool. The pool plumbing uses conventional 1.5" PVC piping to provide adequate flow to an automatic pool cleaner. The homeowner operated the one horse power pool pump for seven hours per day during winter months and 10 hours per day during the rest of the year. Based on previous field research, we knew that large efficiency opportunities existed within this end-use (Messenger and Hays, 1984).

The measured pool pump electricity at the study home during a nine month baseline period was large: 9.3 kWh per day or 3,386 kWh/yr. We measured 37.4 total feet of head on the pool's circulation piping and calculated that a 3/4 horsepower pump would adequately provide the flow needed for the operation of the pool cleaner. The existing pool pump was an *A. 0. Smith C48K2PUlOl* with a continuously running electrical demand of approximately 1.3 kW. We then located a very efficient 3/4 hp pool pump, a *Max-E-Glas PE5DL.* The pump was replaced on March 25, 1996. Average power demand under the operating load is approximately 900 Watts. Figure 11 shows the 15-minute pool pump electrical demand over the monitoring period; Figure 12 shows the same data averaged over the daily profile.

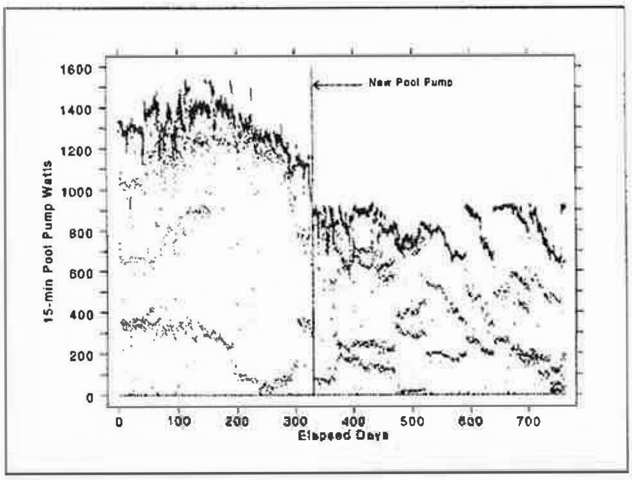


Figure 11. Time series data showing pool pump electrical demand over monitoring period before and after replacement.

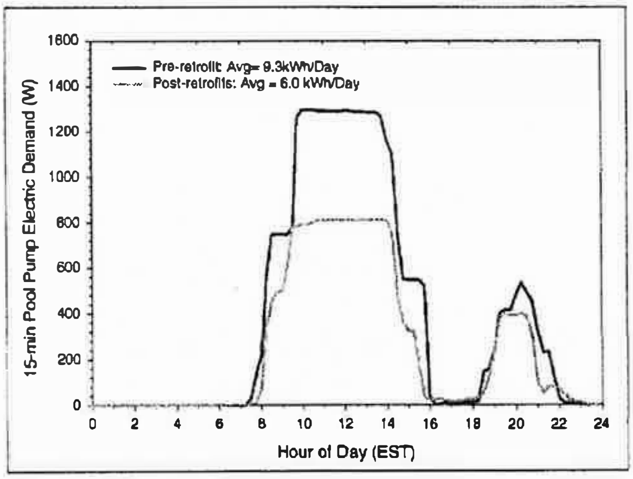


Figure 12. Average daily profile of pool pump electricity demand in year before and after retrofit.

Since retrofit, pool pump energy averaged 6.0 kWh/day – savings of approximately 35%, or about 1,210 kWh/yr ($103). Since the cost of the new pump was $320, and contractors will install such equipment for approximately $50, the payback on such an improvement is less than four years. The automatic pool cleaner operated acceptably with the new pump; the homeowner noted no difference in its performance in the period after the installation.

Super-Efficient Refrigerator

Replacing existing inefficient refrigerators with more efficient models is a proven method to reduce residential energy use (Parker and Stedman, 1992). The existing refrigerator at the site ,was typical of many Florida homes: a 23.5 cubic foot *General Electric TFF 24RC* side-by-side refrigerator. Manufactured in 1983, the DOE energy guide label annual energy use for this unit was 1,748 kWh. Experience indicated that refrigerator energy use in Florida homes is often 10-20% greater than the label values due to the higher interior temperatures. However, we were surprised consumption which averaged 8.33 kWh per day for an annual energy use of 3,040 kWh per year - 15% of household consumption!

Figure 13 shows that the energy use of the existing unit rose in the late summer of 1995 when the anti-sweat case heaters were switched on. Analysis showed that consumption prior to activation of the heaters (turning off the "Energy Miser" switch) was 7.0 kWh/day, increasing to 9.0 kWh/day with the heaters on.

On February 16th, 1996 a new 25 cubic foot *Whirlpool ED25PS*D*O* refrigerator was installed. This model won a utility sponsored competition for the Super Efficient Refrigerator Program (SERP). The new side-by-side refrigerator was slightly larger than the original unit, but included the same through-the-door features. Measured consumption after its installation over an entire year was dramatically lower, averaging just 2.32 kWh per day or an estimated 849 kWh per year. Although this is greater than the estimated energy use for the SERP refrigerator (641 kWh/year), the savings still represent a 73% reduction in energy use from the refrigerator. The consumption profile of the two refrigerators over the 24-hour cycle is shown in Figure 14. With a measured energy savings of 2,191 kWh/year against a purchase cost of $1000, annual savings are estimated at $186 with a simple payback of 5.4 years.

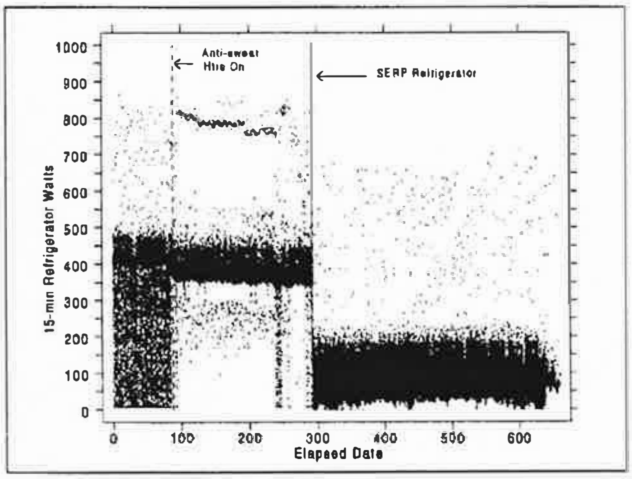


Figure 13. Time series of refrigerator electricity demand over monitoring period, pre and post installation of high efficiency unit.

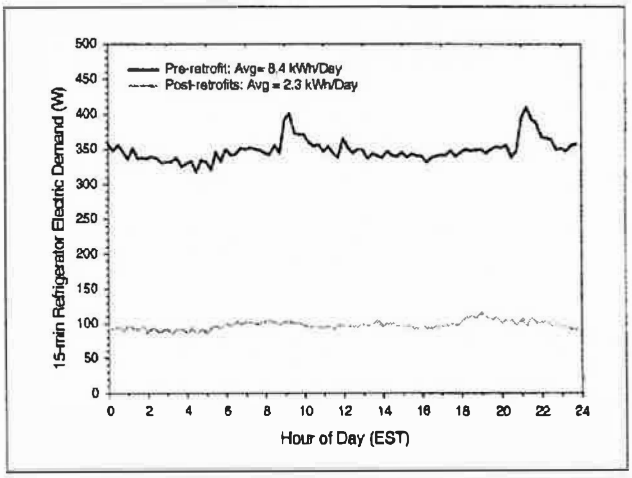


Figure 14. Average daily refrigerator electric load profile in year before and after replacement.

Increased Attic Ventilation

The hipped roof attic has small non-continuous screen soffit vents under the eaves of the roof, but no ridge vents. The roofs black asphalt shingles get very hot; we measured surface temperatures in excess of 180°F. During baseline monitoring, we recorded attic air temperatures of 143°F on the hottest days in July 1995. The ceiling has 6 inches blown fiberglass insulation irregularly distributed over the attic floor.

The actual R-value is not probably greater than R-15 as installed. Also, missing knee wall insulation in the cathedral ceilings results in further compromise to thermal performance.

With the attic radiant barrier installed in July of 1995, the peak attic air temperature dropped by almost 20°F and produced measurable savings in air conditioning consumption. However, we were still displeased with the magnitude of the attic temperatures (peaks 120°F on clear summer days). To try to further reduce this load, on August 12, 1996 we added approximately 60 lineal of ridge vent. A two inch wide strip was cut from the ridge apex and the mesh ridge vent was then placed over the gap. The mesh was then topped off by shingles. According to the manufacturer, the effective free vent area is 16.9 square inches per lineal foot. On this basis, the added vent area is 7.0 square feet.

To gauge effectiveness, we compared the difference between the attic air temperature and measured ambient air temperature for one month before and after adding attic ventilation (house already had a radiant barrier). The result over a 24 hour profile is shown in Figure 15. The average temperature difference between the attic and ambient over the daily cycle fell by 1.51°F, although the peak afternoon air temperature was lowered by 4.4°F. Assuming, 1500 square feet of conditioned attic floor area at R-19 and 375 square feet of R-4 duct, the change in the peak conductance is approximately 800 Btu/hr. With the given efficiency of the air conditioner (~13 Btu/W at peak conditions), this represents approximately a potential 60 W (2%) reduction in peak AC power. Annual energy savings from the retrofit were estimated at approximately 1% (45 kWh) based on a regression analysis.

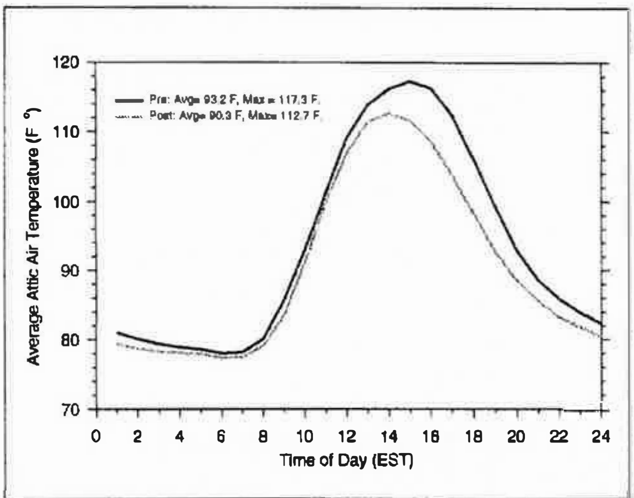


Figure 15. Average attic air temperature in months pre and post addition of attic ridge vent, July- Sept. 1996

Retrofit of Home Lighting

A previous study had already demonstrated the savings available from reductions to home lighting energy use (Parker and Schrum, 1996). A comprehensive lighting inventory on the house was performed as summarized in Table 2. The home contained 59 lamps under 17 controls (switches). The total connected lighting load was 3,700 W. In June of 1996, after a year long period of baseline monitoring, we substituted high efficiency compact fluorescent lamps and other high efficiency fixtures for the more frequently used lamps. The connected lighting load was reduced to 1.5 kW or by 60%.

The miscellaneous electrical loads at the site were determined by subtracting the various measured end-uses from the total load. What was left over is lighting loads, energy use from the stereo, clocks, rechargeable phone, etc.

One problem with the subtraction method of monitoring (major end uses are subtracted from total load) is that the residual left over include lighting as well as numerous other loads, such as the three TVs, two VCRs, home computer, electric clocks, dishwashers, vacuum cleaners etc. Consequently, in addition to the electrical metering, individual time-of-use light loggers were deployed on each of the lighting fixtures in the home to establish actual on-time of each. Several of the TOU- plug loggers were also used on plug-in fixtures. The idea was to determine how the "pure" lighting loads compared with those determined by subtraction.

Table 2. Household Lighting Inventory

Switch	Area	Lamp/Fixture	Total Watts	Replacement Type
	Kitchen			
1	Counter Lighting	50 W Halogen (3)	150	No change
2	Overhead Lighting	F40CW T12 (4)	190	F32 T8 (2)= 78W
	Dining			
3	Over Table	50 W Halogen (3)	150	No change
4	Aquarium Lamps	FR40T12 I (2)	200	F32 T8 (2)= 60W
	Living Room			
5	Floor Lamp Torchiere	475 W Halogen (1)	475	39 W CFL (2)= 78W
6	Track lighting	50 W Halogen (4)	200	No change
	Study			
7	Floor Lamp Torchiere	475 W Halogen (1)	475	39 W CFL
8	Ceiling fan light	60 W I (1)	60	15 W CFL
	Hallway			
9	Overhead flood lamps	75 W PAR (2)	150	16 W CFL (2)=32W
	Guest Bedroom			
10	Ceiling fan light	60 W I (1)	60	15 W CFL (1)
	Master Bedroom			
11	Wall sconces	150 W Halogen (2)	300	No change
	Bath			
12	Vanity Lamps	40 W I Globes (12)	480	15 W CFL (4)=60W
	Master Bath			
13	Vanity Lighting	40 W I (12)	480	15 W Globes (4)=60W
	Garage			
14	General Overhead	F40CW T12 (4)	190	F32 T8 (4)= 120 W
24	Garage Door Lamp	40 W I (2)	80	No change
	Outdoor Lighting			
15	Front Porch	25 W I Globe (1)	25	15 W CFL Globe
16	Back Porch	25 W I Globe (1)	25	15 W CFL Globe
17	Pool lighting	I lamp	Unknown	No change**

** Homeowner indicated these were almost never used.

The light logger monitoring began in February 1996 and extended through May of the same year. An example of the recorded data (Figure 16), shows the average on-time of the overhead kitchen lighting (190 Watts total). The composite load from all of the light loggers was then aggregated depending on the wattage of the lighting load on each. These loads were then used to create daily lighting load profiles for each room in the home as shown in the attached figures. The comparative data from both the "miscellaneous"

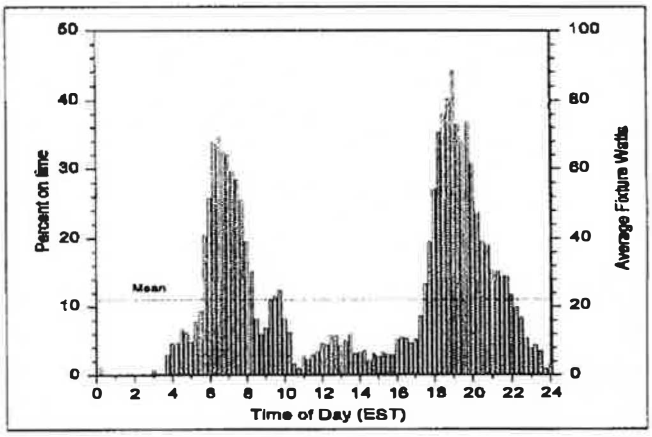


Figure 16. Measured kitchen lighting Feb. - May 1996.

load data captured by the central data logger was then compared with that recorded by the individual lighting loggers.

The homeowners used modern floor standing torchiere lamps to provide a portion of the lighting in the home. One was used in the main living room with the other in the study. These lamps have become very popular due to their low expense. Although providing bright indirect illumination, the lamps use considerable electricity. We used a digital power analyzer to measure the electrical use of the torchieres. At full output they each drew 475 Watts. Based on this information and the estimated load hours we calculate that 3 kWh/day is due to the halogen torchieres. The homeowner indicated that both of the torchieres were typically used in evenings, a demand of around 900 Watts. Moreover, with both on there is a 3,000 Btu/hr sensible load on the air conditioner. To address end-use, we constructed three compact fluorescent lamp (CFL) substitutes for the existing torchieres. The prototypes were designed around the General Electric D-lamp with an electrical demand of 39 W. Photometric testing showed that two of the CFL torchieres would provide equal or greater light output than the single 475 W torchiere used in the living room.

We installed the prototypes on June 29th 1996. Interestingly, the homeowner preferred the light from the new torchieres to the previous single model. We also changed out the kitchen lighting from a fixture with four-tube F40CW T12s with magnetic ballasts to two F32 T8s with a high output ballast and reflectors to obtain more light from the fixture. CFLs of various sizes and types we installed elsewhere with the lighting change out. The first phase of the change was done on May 30th, 1996, with the torchieres altered a month later. The last incandescent lamps were replaced on August 3rd.

Table 3 shows both the average number of hours which each major fixture was used within the various spaces along with the fraction of the measured daily lighting energy. Pre-retrofit lighting energy consumption was on the order of 2,550 kWh/year. The table also shows the estimated savings from using the product of the recorded fixture on-time from the lighting loggers times the wattage reduction. This method of estimation calculates a daily savings of 1,402 kWh – or roughly 45% of pre-retrofit consumption.

Table 3. Fraction of Daily Electric Lighting Energy used by Room and Fixtures

Location	Daily kWh (Pre-retrofit)	Avg No.* Hours Day	Retrofit W Reduction	Estimated Savings (kWh/day)
Outdoor	0.32	6.4	20	0.13
Kitchen	0.49	2.6	112	0.29
Kitchen counter	0.09	0.6	0	0.00
Garage	0.02	0.1	70	0.01
Master Bedroom	1.29	4.3	0	0.00
Study Torchiere	0.52	1.1	436	0.48
Study fan light	0.03	0.6	45	0.03
Guest Bedroom	0.02	0.3	45	0.01
Dining Room	0.05	0.3	105	0.03
Living room torchiere	1.20	2.5	397	0.99
Guest bath	0.19	0.4	260	0.10
Aquarium lighting	1.68	8.4	140	1.18
Master bath	1.01	2.1	260	0.55
Hallway	0.05	0.3	118	0.04
Total	7.00			3.84

* Measured by light logger.

Subtracting all the major electrical end-use from total consumption at the study home, lighting and measured miscellaneous loads average 14.2 kWh/day or 5,253 kWh per year. At 25% of annual use, this is the second largest end use in the home after air conditioning (40%). The data analysis above suggests that approximately half of this amorphous end-use is made up of lighting with a peak at 9 PM of approximately 1.3 kW. Data analysis in the year before and after the lighting retrofit showed that miscellaneous energy consumption dropped from 5,253 kWh to 3,913 kWh - a reduction of 1,340 kWh. This is very close to the estimate derived from using the light loggers.

A comparison of the miscellaneous energy use at the household before and after the lighting retrofit is shown in Figure 17. Not surprisingly, the plot shows that the lighting energy savings are concentrated during the evening hours. The lesser reduction during the morning is due to the fact that only a portion of the bathroom vanity and bedroom lighting could be retrofit.

The economics of the lighting retrofit measure was attractive. With an overall cost of approximately $400 and a savings of $115/yr, the measure has a simple payback of under four years.

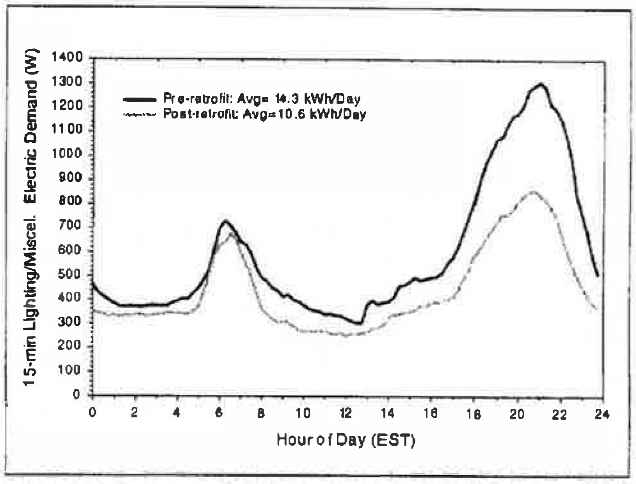


Figure 17. Measured lighting and miscellaneous load electrical demand profile pre and post lighting retrofit.

Ceiling Fans

Ceiling fans make up another sizeable segment of household energy use in Florida residences. Typical homes have 4 - 5 ceiling fans and there are over 30 million fans in use around the state. Previous analysis has shown that ceiling fans can either save cooling energy or use more energy than is saved depending on usage patterns and thermostat set-up behavior (James et al., 1996). Typical users reported having 2.5 fans on at any one time with the average fan operated 13.4 hours per day. We suspected, however, that the study homeowner would use their fans much less since they were keenly aware of the implications of leaving ceiling fans on for long periods in unoccupied rooms.

We monitored the on-time of the five ceiling fans in the household using motor loggers. The loggers were left in place for a full year. Table 4 provides the measured data.

Table 4. Measure Ceiling Fan Use

Fan Room Location	Hours Per Day	Estimated Annual kWh
Dining room	0.3	4
Living room	2.1	31
Study	1.1	16
Master Bedroom	8.6	126
Guest Bedroom	1.2	18
Average	2.7	195

The data collected from the loggers showed an average fan use of 2.7 hours per day in the household, ranging from 0.3 hours for the fan in the dining area to 8.6 hours per day for the fan in the master bedroom. Assuming an average fan power draw of 40 W, this equates to approximately 200 kWh used annually to operate the household's ceiling fans. Figure 18 shows the on-time profile for the ceiling fan in the master bedroom of the home.[4]

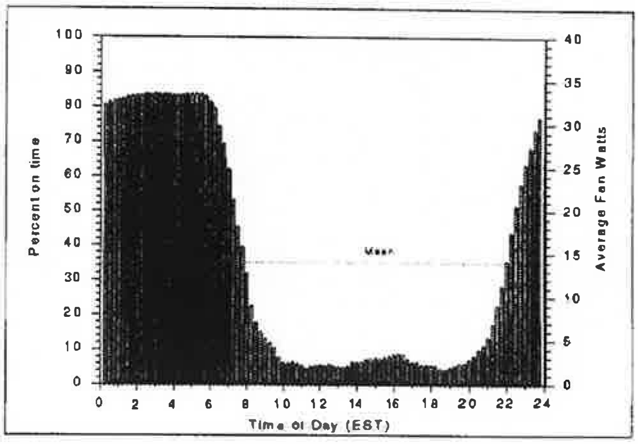


Figure 18. Measured master bedroom ceiling fan use profile from August 1996 - August 1997.

Miscellaneous Loads

Since lighting was measured at approximately 2,550 kWh per year and ceiling fans approximately 200 kWh/year, over 2,500 kWh or about 13% of total energy use is unaccounted by the measured end uses. Typically, miscellaneous energy use consists of loads from appliances too small to otherwise consider as separate end-uses. Loss in house wiring and ground fault interrupt plugs, are also unaccounted for; this may be as large as 1% of total loads.

To obtain an idea of magnitude, we metered a variety of miscellaneous equipment in the home with the digital power analyzer. We also used plug loggers to record the on-times (Table 5).

Table 5. Measured Miscellaneous Electricity Loads in Site Home

Item	Watts	Hours/Day	Annual kWh
Security system	15.0	24.0	131
Portable phone #1	1.6	24.0	14
Portable phone #2	1.2	24.0	11
100 gallon aquarium pump	41.0	24.0	359
Entertainment center	210.0	6.0	460
- above when off	18.0	18.0	118
Master bedroom TV	150.0	1.51	83
- above when off	5.0	22.5	41
Portable radio	7.0	1.0	3
- above when off	2.0	23.0	17
Microwave oven	600.0	0.120	26
Microwave clock	5.0	23.88	43
Toaster oven	460.0	0.10	17
Espresso maker	360.0	0.10	13
Monitor & computer	115.0	1.49	63
Laser printer	250.0	1.61	146
			1,545 kWh or 4.2 kWh/day

The demand of the items that are constantly on, but not in use was surprisingly large: 43 W (375 kWh/yr) or 4% of total

[4] A sister study used motor loggers to measure the use of ceiling fans in a home where the occupants are more typical and do not always exercise vigilant control over fan operation. In this household, the average fan use of five installed fans was 12.6 hours per day (very close to the survey average) with an estimated annual energy consumption of 920 kWh! Assuming that this is a more typical circumstance, ceiling fans may represent an average of 6% of total annual residential energy consumption (~14,900 kWh) in the typical single family Florida home. Also, if only a third of the 30 million ceiling fans in the state were operating during the utility summer peak hour, they would represent a aggregate power demand of approximately 400 MW!

consumption. The so called "phantom loads" from power packs, clocks and timers – all increasingly common in U.S. households – were half of this load.[5]

Economics

The objective of the project was to explore the maximum feasible energy savings in an existing Florida residence and as such was not intended to be economic. Nevertheless, we did track the cost of the various measures installed to access economic performance could be performed. Table 6 lists the various measures, their costs, estimated savings and simple payback. The package of installed measures have a simple payback of under 11 years corresponding to an after-tax simple rate of return on investment of about 9.5%. It is also noteworthy that these costs for discretionary replacement of equipment are pessimistic. If the efficient equipment was chosen at the time of natural equipment replacement, the economics of several of the measures would have been much more attractive.

Table 6. Economics of Installed Measures

Retrofit Measure Description	Installed Cost ($)	Estimated Annual Savings kWh ($)	Simple Payback (Years)
Radiant barrier system (RBS)	$1084	430 ($37)	29.3
High efficiency air conditioner	$3587†	3260 ($277)	12.9
Solar water heater	$1649	950 ($81)	20.3
Efficient pool pump	$ 320	1210 ($103)	3.1
High efficiency refrigerator	$ 999	2190 ($186)	5.4
High efficiency lighting	$ 400	1340 ($115)	3.5
Attic ventilation	$ 410	45 ($4)	113.9
Total	$8449	9375 ($800)	10.6

† includes utility rebate of $484

Conclusions

A graphic display of the changes in energy consumption over the monitoring period are shown in Figure 19. The measured daily profile of reduction over the entire year was approximately 45% as shown in Figure 20. When using the utility bills in the year previous to the monitoring, the reduction was about 40% (Figure 21). In any case, the projected demonstrated the technical feasibility of reducing household energy use between 40 and 45%, depending on the basis of the reference period. The absolute energy savings were between 8,000 and 10,000 kWh/year.

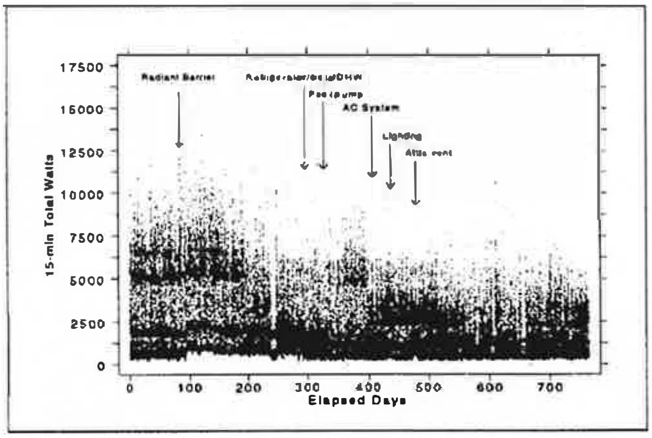
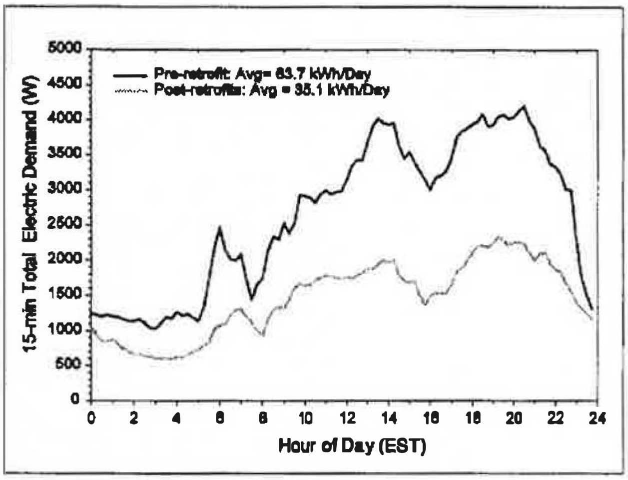


Figure 19. Measured total household electrical demand over two-year monitoring period.

[5] The magnitude of this miscellaneous energy use should not be underestimated. Assuming 50 Watts of "phantom loads" in the average Florida household (over six million), this would represent a constant electrical generation requirement of 300 MW – nearly equal to the output of a new combined cycle electric power plant.



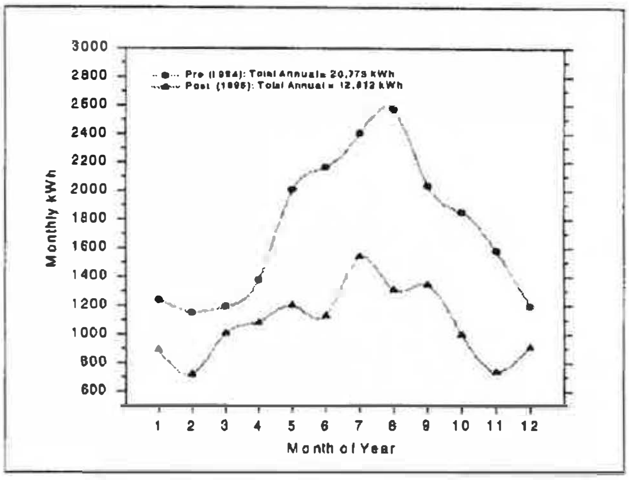


Figure 20. Measured average daily total electric load profile in years pre and post retrofits.

Figure 21. Recorded monthly energy use before and after retrofit.

Energy savings varied by end-use: savings were over 42% for space cooling and over 70% for water heating and refrigeration. Lighting energy was cut by more than 50% and pool pump energy by 35%.

The primary project intent was to demonstrate maximum feasible energy reductions in existing Florida housing rather than economically justifiable levels. Even so, the economics were not entirely unattractive. The cost of the overall measures was approximately $8,450. With a measured annual utility cost reduction of $680 - $880, the simple payback of the collection of improvements was approximately 11 years. Had the improvements been made at the time of natural equipment replacement the economics would have been much more advantageous.

One of the most important conclusions drawn from the study was that measures seldom considered in residential energy assessments – pool pumps, lighting and refrigeration – were the most cost effective to retrofit. A large portion of the cooling energy savings from the AC replacement were due to improved cooling system evaporator air flow and the large improvement to space cooling efficiency.

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