IMPACT OF REFLECTIVE ROOFING ON COOLING ELECTRICAL USE AND PEAK DEMAND IN A FLORIDA RETAIL MALL

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Introduction

Architects in hot climates have long recognized that reflective roof colors can reduce building cooling load. Experimentation spanning nearly three decades has shown that white roofing surfaces can significantly reduce surface temperatures and cooling loads (Givoni and Hoffmann, 1968; Reagan and Acklam, 1979; Griggs and Shipp, 1988; Anderson, 1989; Anderson et al., 1991 and Bansal et al., 1992). More importantly, measured cooling energy savings of white surfaces have been significant in California's climate (Akbari et al., 1991, 1992, 1997).

In Florida, field research by the Florida Solar Energy Center (FSEC) since 1993 has quantified the impact of reflective roof coatings on sub-metered air conditioning (AC) consumption in tests in a dozen occupied homes (Parker et al., 1993; 1994; 1995; 1997). The coatings were applied to the roofs of each home in mid-summer after a month-long period of monitoring during which meteorological conditions, building temperatures and AC energy use were recorded. Using weather periods with similar temperatures and solar insolation, air conditioning energy use was reduced by 10% - 43% in the homes. The average drop in space cooling energy use was about 7.4 kWh/day or 19% of the pre-application air conditioning consumption.

Unfortunately, until this project there has been little objective testing of the impact of roof whitening on the AC load of commercial buildings in Florida. Two demonstration sites have been monitored. The first was an elementary school in Cocoa Beach, Florida, which was monitored for a year before and after a white roof coating was applied. A final report on this project was published in the *CADDET Newsletter* (Parker et al., 1996a, b). The project demonstrated a 10% annual savings in chiller energy with a 30% reduction in peak cooling electrical demand. This paper summarizes the findings from the second demonstration at a commercial strip mall.

Description of Test Site

The site is on U.S. Highway 1 in Cocoa, Florida (Figure 1); the metal building is 12,500 square feet with a total of eight shops. Each storefront is approximately 25 x 50' with large glazed storefronts facing east. The storefronts consist of a bagel shop, a real estate office, an insurance office, a cell phone store, a bookstore, a bedding store, and a daycare center. The last storefront was vacant.

Figure 1. Strip mall used as project test site. There is a large section of east facing glass in each storefront.

The roof is un-surfaced galvalum metal roofing over metal studs with R-11 insulation suspended underneath on purlins (Figure 2). Dropped acoustic ceiling panels are located in each bay with the plenum containing the air handler and thermal distribution system. R-11 fiberglass batts are located on above the acoustic insulation panels. All of the shops are served by 3-4 ton split system ACs. The air handlers are located in the roof plenum space with the exterior compressors on concrete pads to the rear of the wall behind each shop. Each shop is individually metered.

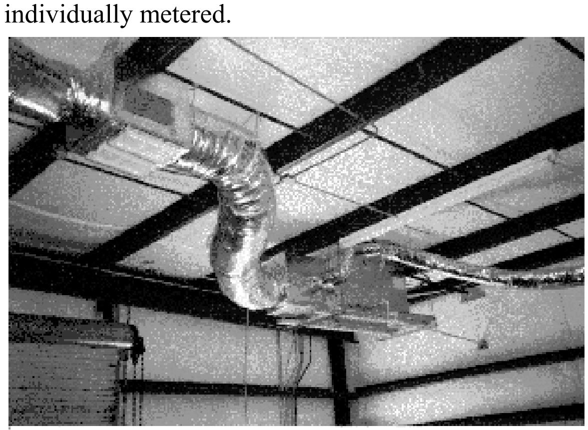


Figure 2. View of roof plenum showing R-11 batts on purlins separated by metal studs with air handler and thermal distribution system located inside the plenum. Acoustic ceiling tiles are typically suspended on the metal frame just below the air handler.

Experimental Plan

To isolate the impact of adding a reflective roof surface, a before-and-after experimental protocol was used. With this experimental approach, a period of base line data is collected on the space cooling performance at the facility. The data includes meteorological conditions and space cooling energy use. Preferably, this data would cover a long period of time, or at least contain good data spanning a large portion of the space cooling season. After the base line data is collected, the roofs of the various shops is altered to white at mid cooling season and the results on space cooling monitoring during the post period. With this approach, both the pre and post periods should contain sufficient data from the cooling season to obtain long periods (several weeks) with matching weather conditions for comparison.

To obtain immediate results from the project, we planned to alter the roof color over two phases. In Phase I we would monitor all of the shops in their baseline condition for half of the summer of 1996. Two of the northernmost shops would then be changed to a white roof system at mid-summer. Their performance could then be compared with that in the pre-surfacing period, as well as with other non-surfaced shops in the post period. Thus, Phase I would provide immediate data on summer cooling related performance on two of the shops. The other six shops would be monitored for a full year in their baseline condition and then be altered in Phase II in the mid-summer in 1997. This would allow long term full year pre and post data for these shops by the fall of 1998. We also desired to examine how much degradation of the Phase I re-surfacing could be observed after one year.

Monitoring Protocol and Instrumentation

Instrumentation was installed on site from June 21 - 27th, 1996, with continuous data collection beginning on the later date. Over 50 channels of temperature, meteorology and AC consumption data were recorded. Meteorological conditions monitored at the site included ambient temperature, relative humidity, insolation and wind speed. Temperature readings were obtained at three points on the roof consisting of the metal roof surface, underside surface of the insulation, the plenum air temperature, and the conditioned interior air temperatures.

Temperature measurements were obtained using calibrated, type-T, copper-constantan thermocouple wire installed at various points in the building. The ambient air sensor was shielded from direct radiation by placing it inside of a vented enclosure. Capacitive-type humidity transmitters provided temperature compensated RH readings. Insolation was measured using a horizontally mounted silicon-cell pyranometer located on the rooftop. Electrical power consumption was assessed by a 50-amp pulse-initiating power meters. The amount of power consumed by the air conditioners were monitored for each store front to determine the electrical demand. Heating energy consumption was not measured. A multi-channel datalogger was used to convert the analog and pulse instrument outputs to digital format. Data were read at 5 second intervals and integrated or totalized values were recorded by the datalogger every 15 minutes.

Reflectivity Measurements

Site roof reflectivity measurements used an inverted pyronometer method developed by previous investigators (Reagan and Aklam, 1979 and Taha et al., 1992). The measurements were made with an *Eppley Precision Spectral Pyranometer* (PSP). Measured roof reflectivity at the strip mall was changed from 28.8 (±0.4)% to 75.3 (±3.2)% as measured before and after the first coating. These values represent the averages of 12 repetitions of these measurements across the surface of the roof. Examination of the exposed exterior roof surface with an infrared camera at mid-day on June 9th, 1996 revealed temperatures of over 150°F. Examination of the thermal conditions on the building interior showed elevations of 5°F above room conditions on the insulation surface and as much as 15°F on the metal studs.

Roof Whitening: Phase I

The first roof coating was applied to a section of the mall roof after a month of base data had been collected. The coated section covered the two northern most shops within the mall. This consisted of the bagel shop and the insurance office immediately adjacent. The first coat was applied on August 11th with second coat on August 25th, 1996.

A commercially available coating product was used for the re-surfacing. The coating was applied to the corrugated metal roof surface by using an aerated sprayer. The prime coat was applied to a thickness of 13 - 14 mills, the reflective top coat was applied to a similar thickness. The application coverage amounted to approximately 120 gallons of material to coat each store's roof (2500 ft^2).

Roof Whitening: Phase II

The remaining five shops received their white coating on July 30th, 1997. All of the remaining roof sections were made white, save for the single unoccupied shop on the extreme south end was maintained as a control. Final coating application was complete on August 11th. At the same time the reflectance of the newly installed coating was applied, we also examined the change in reflectance at the year-old section. We found little evidence of degradation of the white surface installed a year previous. We measured an *in situ* solar reflectance of 72.6 (±10.3)% on August 6th, 1997 against the freshly coated value a year before of 75.3 (±3.2)%.

The un-coated metal roof had a measured reflectance of 29.6%. The newly surfaced section of the roof had a solar reflectance of 77.4 (±6.0)%. Figure 3 shows the coating being applied to the remaining segment of the roof.

Figure 3. Phase II on roof whitening on July 30, 1997.

Little degradation of the white surface was seen after one year. Although the difference in the means was 2.7% lower after a year of exposure, the value is within the statistical uncertainty of the measurements.

Experimental Results: Phase I

Initial examination of the data from the change to the two northernmost shops showed substantially lower roof, plenum and interior temperatures. Using the entire month of baseline data we searched for a period post treatment with very similar average ambient air temperature and solar insolation. Table 1 shows the comparison of the key performance parameters for the pre and post periods for the two shops when using this approach. Figures 4 - 7 graphically show how the temperatures and AC use varied in the two initially re-surfaced store fronts. Average AC energy reduction in the two shops in Phase I was 6.8 kWh/day or 16%. The average demand reduction during the utility peak hour was 0.45 kW or 21%.

Table 1
Comparative Average Performance Before and After Roof Whitening
Before: June 27 - July 26, 1996; After: Aug. 19 - Sept. 10, 1996
Weather Conditions

Ambient Temperature (°F)	Relative Humidity (%)	Wind Speed (m/s)	Solar Irradiance (W/m^2)	Roof Temperature (°F)
81.3°	78.8	2.77	240	92.8°
81.2°	79.6	2.90	235	79.1°
0.1°	-0.8°	-0.13°	5.0°	13.7°

Store Front	Plenum Temp.	Interior Temp.	AC/kWh Day	Peak Plenum Temp. (°F)	Peak Interior Temp. (°F)	AC Pk kW
Bagel Shop						
Before	84.6°	74.8°	48.18	92.5°	75.6°	2.245
After	79.9°	74.9°	41.79	83.8°	74.3°	1.834
Difference	4.7°	-0.1°	6.39	8.3°	1.3°	0.411
Percent			13.3%			18.3%
Realty office						
Before	84.8°	72.7°	37.32	95.4°	73.1°	2.051
After	80.1°	73.4°	30.11	85.0°	74.1°	1.565
Difference	4.7°	-0.70°	7.21	10.4°	-1.0°	0.486
Percent			19.3%			23.7%

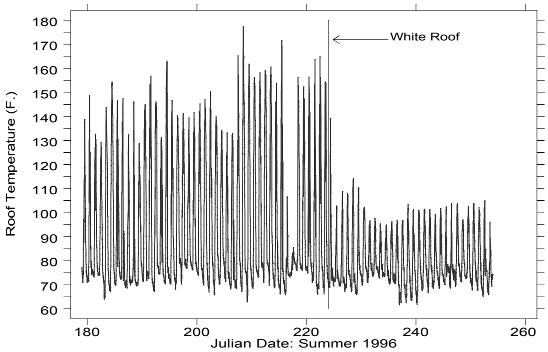


Figure 4. Measured roof surface temperature above the bagel shop before and after roof re-surfacing.

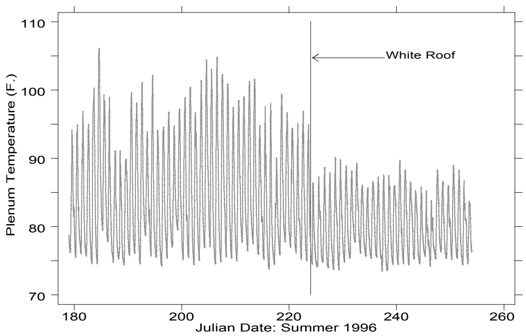


Figure 5. Measured plenum air temperature above the bagel shop before and after roof re-surfacing.

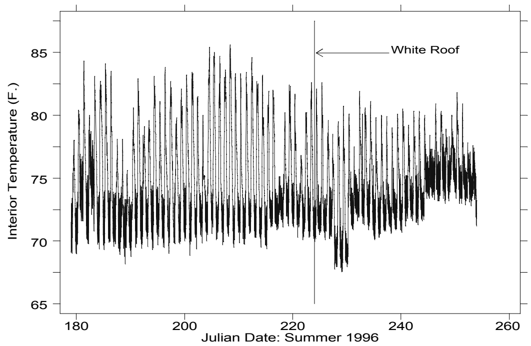


Figure 6. Measured interior air temperature above the bagel shop before and after roof re-surfacing. Note (1) how shop owners had to set the interior temperature higher post treatment to prevent too low temperatures in the morning and (2) the lower variation in interior temperature afterwards.

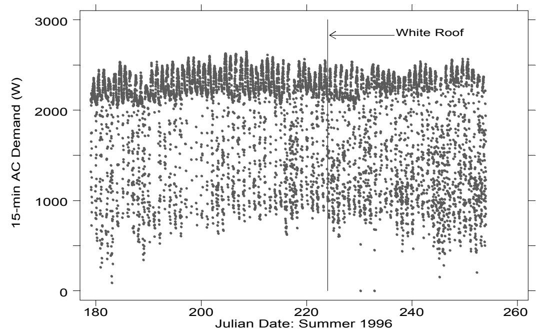


Figure 7. Measured 15-minute AC demand before and after roof re-surfacing at the bagel shop. Note fewer periods of maximum AC demand in the post period.

Figure 8 shows the match of weather conditions in the pre and post period in 1996. Figure 9 shows how the roof surface and plenum thermal conditions were reduced. Finally, Figures 10 and 11 show how air conditioning electric demand and interior comfort conditions were altered from the roof resurfacing in the bagel shop and realty office, respectively. AC use was dropped by 13% and 19% in the two shops with peak hour reductions of 18% and 24%. Interior comfort conditions were also improved substantially in the bagel shop.

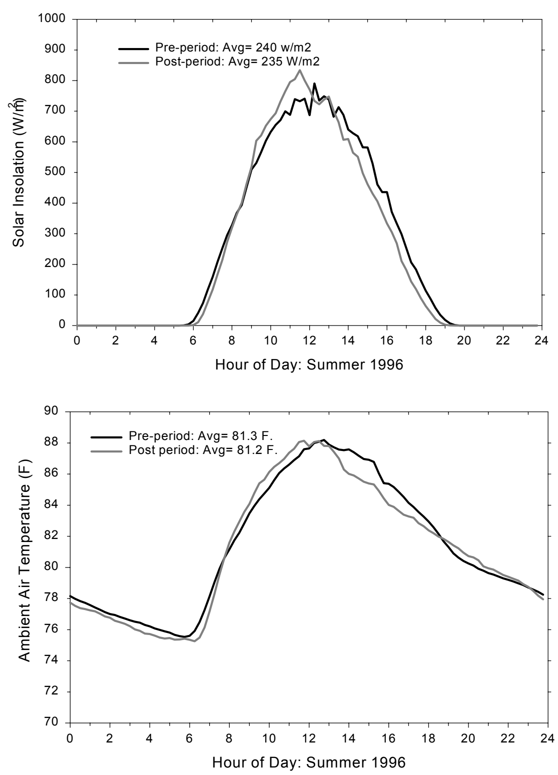
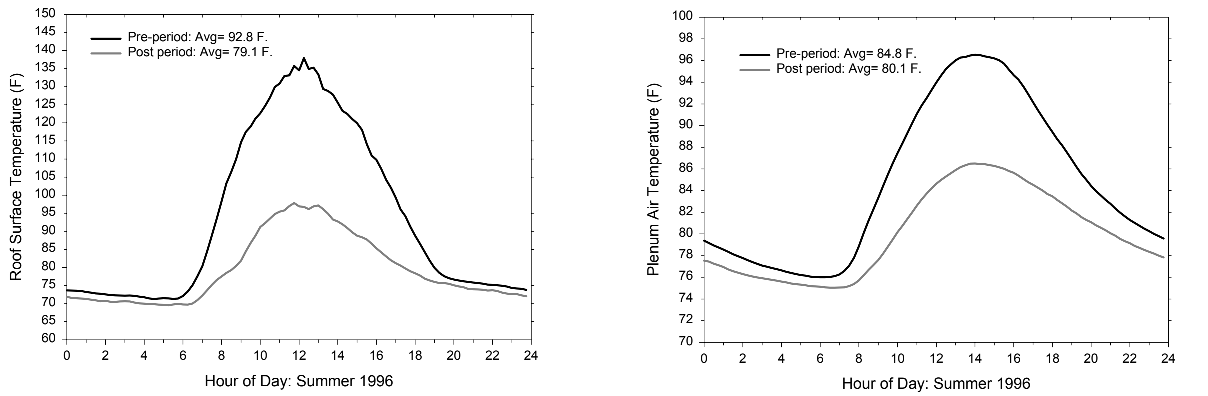


Figure 8. Match of weather data in the pre and post



treatment periods in 1996.

Figure 9. Measured average roof surface (left) and plenum air temperature (right) above the bagel shop in the pre and post period in 1996.

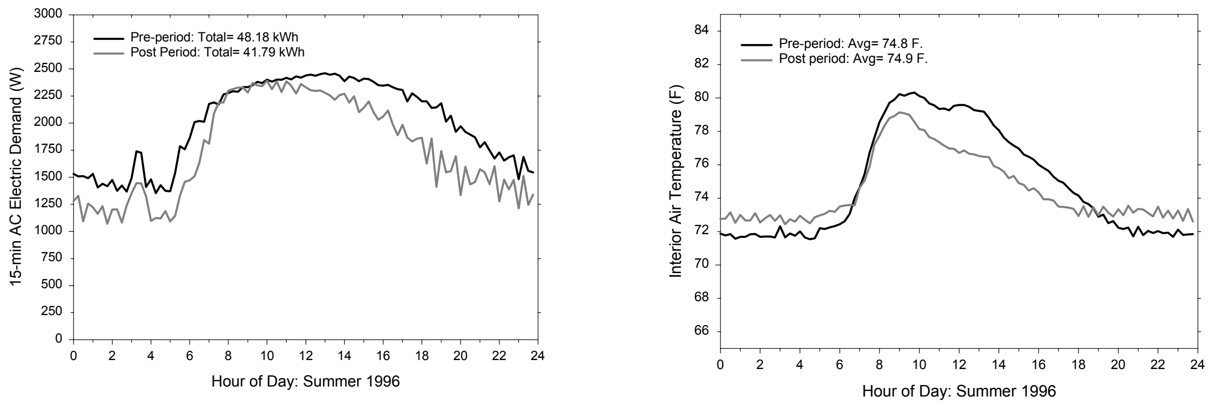


Figure 10. AC demand and interior air temperatures profiles in the bagel shop in the pre and post periods in 1996. Note the influence of the east windows on the early morning temperatures and AC demand. Demand savings from roof treatment begins at roughly 11 AM EST reaching maximum at 6 PM.

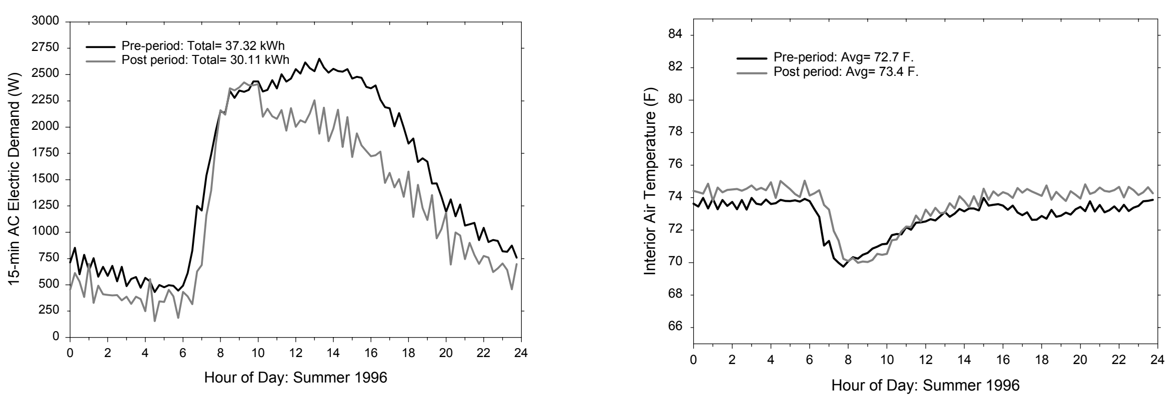


Figure 11. AC demand and interior air temperatures profiles in the realty office in the pre and post periods in 1996. Note the lower interior set temperature used in the morning hours to compensate for heat gain through the east windows. Demand reductions from treatment begins at 11 AM and reaches a maximum at 4 PM.

Phase II Performance

Table 2 describes the statistics for the comparison of the year of pre and post data for the shops whitened during the second year of monitoring. The AC data showed an average 9.4 kWh per day or 33% average reduction in air conditioner energy requirements in the five shops altered in Phase II. Average reductions in electrical demand of 0.9 kW were observed during the utility system peak hour of 5 - 6 PM (4 - 5 PM EST).

Table 2
Comparative Average Performance Before and After Roof Whitening
Before: June 12 - July 30, 1997; After: Aug 12 - Sept. 30, 1997
Weather Conditions in Pre and Post Period

Ambient Temperature (°F)	Relative Humidity (%)	Wind Speed (m/s)	Solar Irradiance (W/m^2)	Roof Temperature (°F)
80.9°	84.8	1.72	235	96.8°
81.0°	83.9	2.02	212	79.4°
-0.1°	1.1%	-0.30	13	17.4°

Store Front	Plenum Temp.	Interior Temp.	AC/kWh Day	Peak Plenum Temp. (°F)	Peak Interior Temp. (°F)	AC Pk[1] kW
Insurance						
Before	88.7°	84.5°	20.15	96.4°	87.1°	0.581
After	80.5°	80.6°	12.27	84.3°	82.1°	0.106
Difference	8.2°	3.9°	7.88	12.1°	5.0°	0.475
Percent			39.1%			81.7%
Cell Phone						
Before	83.3°	77.2°	33.16	90.9°	77.2°	1.810
After	79.1°	77.6°	26.73	83.4°	77.6°	1.323
Difference	4.2°	-0.6°	6.43	7.5°	-0.4°	0.487
Percent			19.4%			26.9%
Book store						
Before	87.2°	82.5°	27.72	94.3°	82.9°	1.298
After	80.6°	79.8°	14.36	84.0°	80.4°	0.555
Difference	6.6°	2.7°	13.36	10.3°	2.5°	0.743
Percent			48.1%			57.2%
Bedding store						
Before	88.7°	86.6°	19.10	97.9°	94.4°[2]	0.313
After	80.6°	80.0°	12.81	85.7°	84.5°	0.090
Difference	8.1°	6.6°	6.29	12.2°	9.9°	0.210
Percent			32.9%			71.2%
Day care						
Before	88.5°	82.5°	53.21	96.5°	84.7°[1]	1.699
After	79.5°	81.9°	40.24	87.5°	81.6°	0.437
Difference	9.0°	0.6°	12.97	9.0°	3.1°	1.262
Percent			24.4%			74.3%

[1] Peak period is 4-5 PM EST; 5-6 PM EDST; these values are the averages during the peak period over it length.

The match of weather conditions in Phase II is shown in Figure 12. Figures 13 - 18 show how air conditioning electric demand and interior comfort conditions were altered from the roof resurfacing in each of the altered shops of the mall.

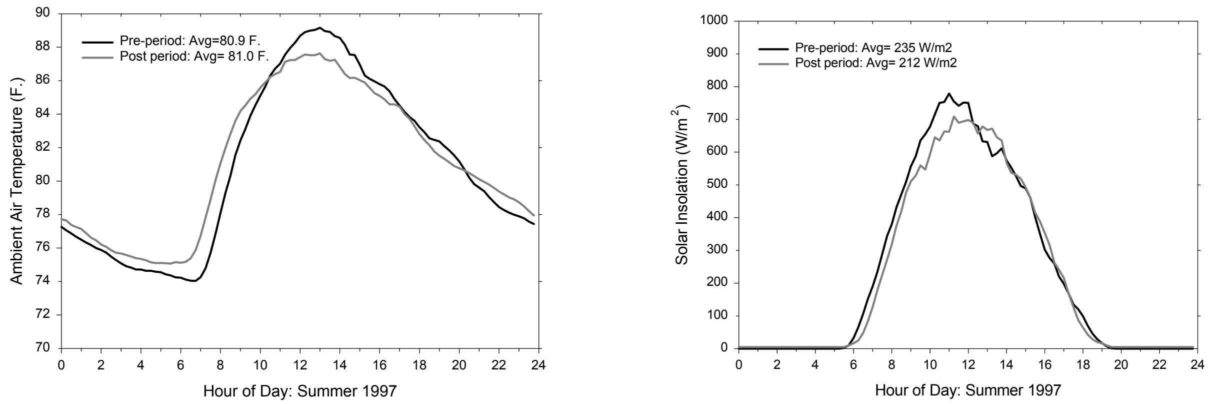


Figure 12. Match of weather data in the pre and post treatment periods of 1997.

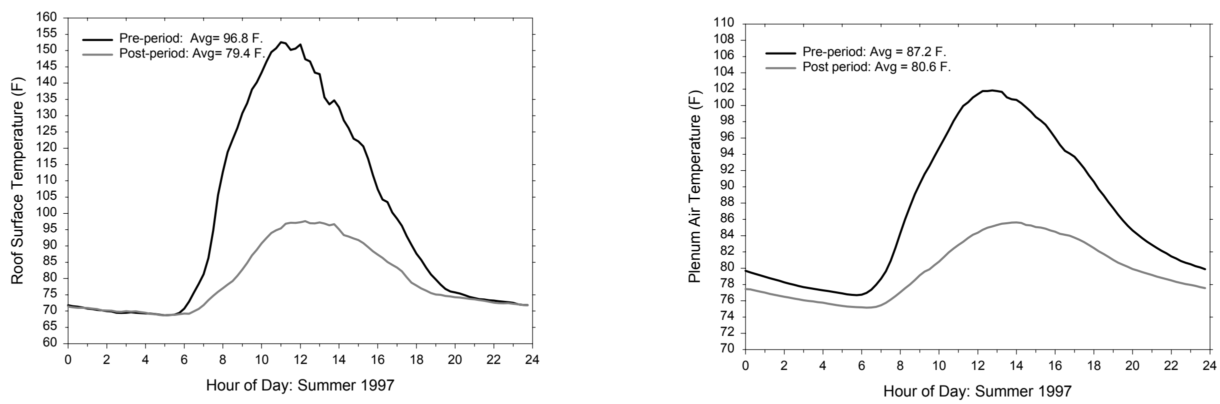


Figure 13. Measured average roof surface (left) and plenum air temperatures (right) above the bookstore in the pre and post period in 1997.

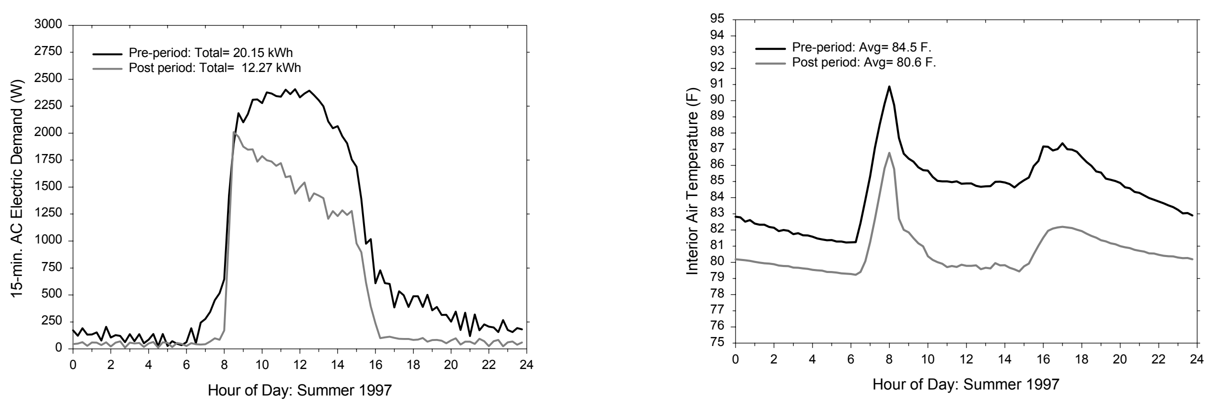


Figure 14. AC demand and interior air temperature profiles in the insurance office in the pre and post treatment periods of 1997. Note the elevation in the interior temperatures in the early morning from the east windows. Maximum demand reduction at 1 PM.

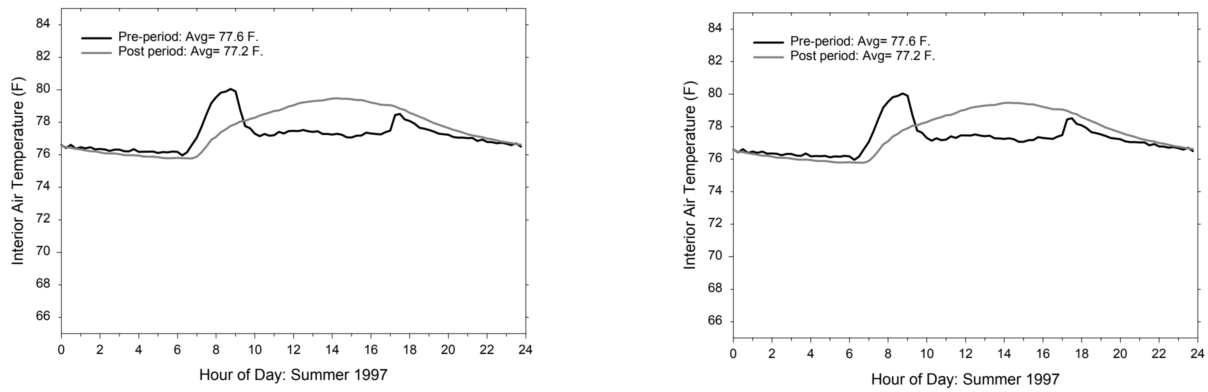


Figure 15. AC demand and interior air temperature profiles in the cell phone store in the pre and post treatment periods of 1997. Maximum demand reduction at 2 PM. Lower temperatures maintained while open (9AM – 5PM) in post period.

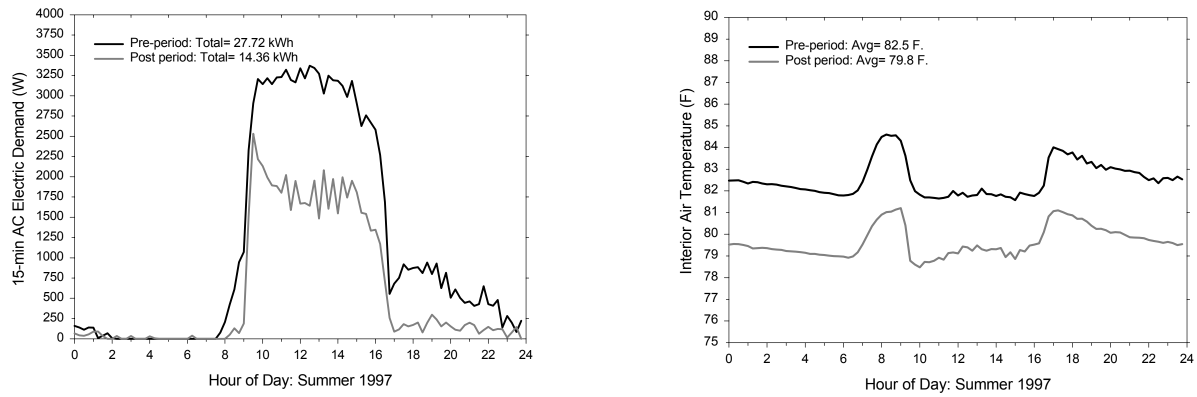


Figure 16. AC demand and interior air temperature profiles in the bookstore in the pre and post treatment periods of 1997. Maximum demand reduction at 12:30 PM. Note much lower temperatures achieved after treatment.

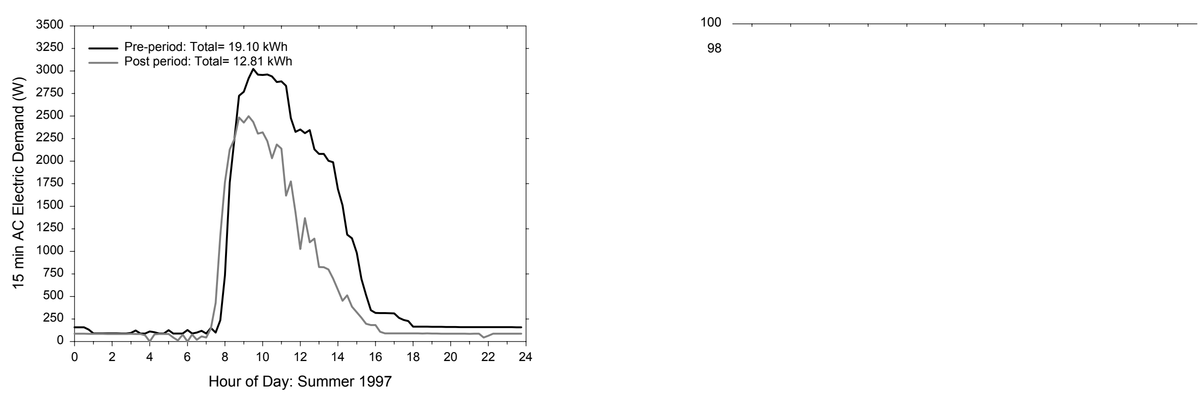


Figure 17. AC demand and interior air temperature profiles in the bedding shop in the pre and post treatment periods of 1997. The store was vacant during the 1997 monitoring period and the landlord had the thermostat set to maintain 95°F or less.

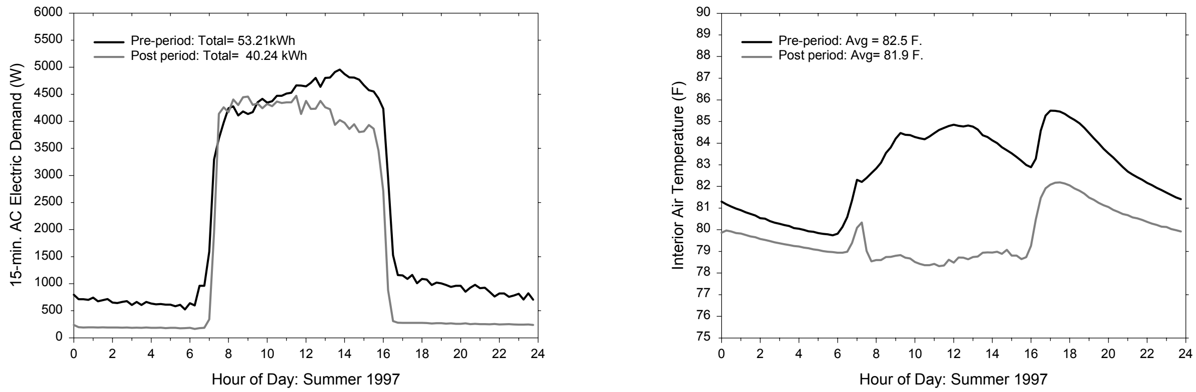


Figure 18. AC demand and interior air temperature profiles in the daycare center in the pre and post treatment periods of 1997. Large savings in spite of substantially improved interior comfort.

Occupant Comfort

Occupants in each retail store were interviewed before and after the roof treatment was whitened. In most cases, the occupants were aware in a change in the thermal comfort conditions after the roof was made white. During the project, the owner of the bagel shop reported that the temperatures during the afternoons seemed lower than before the roof covering — a fact reflected in the collected data. “It helps people to decide to stay and sit down to eat.” Occupants at the realty office reported having to adjust their thermostat upwards “since it was too cool in the mornings”. Although the insurance store receptionist noticed no difference, the bookstore owner noticed that it was much cooler inside when opening for business in the morning. The Nurse Manager at the Alzheimer’s Day Care Center reported the largest perceived impact. “It has made a major difference here. We thought someone had fixed the air conditioner.” The measured average interior air temperatures in the shops were also reduced. The air temperature by the thermostat dropped by an average of 1.8°F and the unconditioned plenum by over 6.5°F — resulting in a cooler ceilings and lower mean radiant temperatures.

Estimated Savings

To estimate annual energy savings of the roof re-surfacing, we summed the measured air conditioning energy in each shop from July 1, 1996 to July 1, 1997 and then used this as a basis for the estimates. The savings percentages developed from the monitoring described in Tables1 and 2 were applied to the result to obtain estimates of annual space cooling energy reduction. Demand savings reflect reductions during the peak summer period between 5 and 6 PM.

Table 3
Measured Annual Air Conditioning Energy Savings

Shop	Measured Annaul kWh	Percent Savings	Estimated Savings	Monthly Demand Savings (kW)
Bagel shop	13,296 *	13.3%	1,768	0.41
Realty office	8,420 *	19.3%	1,625	0.49
Insurance office	4,293	39.1%	1,679	0.48
Cell phone office	6,082	19.4%	1,180	0.49
Book store	3,572	48.1%	1,718	0.74
Bedding store	7,083	32.9%	2,330	0.21
Daycare center	4,347	24.4%	1,061	1.26
Average	6,728	24.1%	1,623	0.58

* Annual space cooling in these two shops was obtained after the roofs had been treated; the values have been increased by the percentage savings to produce an estimate of the pre-treatment space cooling use.

Economics

Based on the average numbers above, we can estimate the annual savings to the shop owners. With a small commercial electricity rate of $0.05/kWh and a demand charge of $9.5/kW, the typical shop owner would see an annual reduction in utility costs of approximately $150. The cost of the white roof application in the project totaled $0.53/ft^2 ($0.33/ft^2 for materials and $0.20 for labor). Given the 2,500 square foot roof area for each store front, the total cost for each shop would average $1,325. With the estimated savings shown above, the simple payback would be approximately nine years.

However, other factors are important to gauge the potential economics of white roof resurfacing. Firstly, a potential utility program would want to target facilities for a light colored roof that were involved in re-roofing. Whereas discretionary change to a white roof costs approximately $0.50/ft^2, the incremental cost for choosing a new white roof system when re-roofing is often negligible. For instance white single ply membranes cost little more than dark ones and white standing seam metal roofs are no more expensive than other colors. Similarly, with modified bitumen roofs, an white roof coating can be substituted for a conventional aluminized coating at very low incremental cost (<$0.10/ft^2).

Results and Discussion

The results for both phases of the project, showed a 25.3% average reduction (8.6 kWh) in summer space cooling energy (34.1 kWh/day to 25.5 kWh/day) in the seven shops with a range of savings of 13 - 48%. The percentage savings varied with the temperature maintained in the shops; those maintaining the lowest interior temperatures saved the least on a percentage basis, although the absolute space cooling energy reductions were more similar ranging from 6.4 to 13.4 kWh/day. The space cooling energy demand reduction was concentrated during the summer afternoon and early evening hours between 11 AM and 7 PM as seen in Figure 19. During the utility coincident peak demand period (defined as 4 - 5 PM EST or 5 - 6 PM EDST) the overall electric demand reduction averaged 592 W (from 1469 to 877 W) or 40.3%.

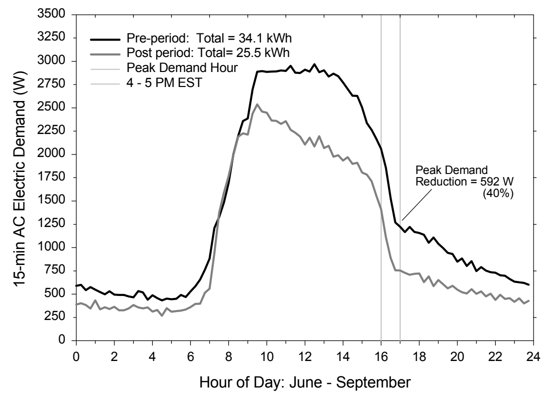


Figure 19. Average AC demand profile during pre and post treatment periods for all seven shops.

Implications for the Design of Utility Programs

Although a site was eventually located for the project, our initial difficulty recruiting participants points out two primary factors that would potentially impact utility programs:

1) Any potential programs must target particular roofing system types that can be easily made white. These will generally *exclude* those facilities committed to the use of ballasted or gravel roofs (although lighter colors of gravel can be chosen, the longevity and performance is unknown).
2) Programs would do best to concentrate on influencing buildings to consider a white roof in new building prior to construction, or otherwise to influence existing buildings where owners are contemplating re-roofing.

Finally, our monitored data showed that savings were greatest in the shops which maintained higher interior temperatures – particularly in facilities which were being air conditioned to the minimum necessary while vacant (the bedding store). This is likely due to the fact that the roof is a much larger part of the cooling load in these facilities. Thus, utility programs targeting air conditioned storage facilities in hot climates could see very large impacts on peak AC demand.

Acknowledgments

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Homes produced with airtight duct systems (around 15% savings in Htg and Cooling Energy)

Palm Harbor Homes	22,000
Southern Energy Homes	8,000
Cavalier Homes	1,000
	= = =
Subtotal	31,000

Technical measures incorporated in BAIHP homes include some or many of the following features - better insulated envelopes (including Structural Insulated Panels and Insulated Concrete Forms), unvented attics, “cool” roofs, advanced air distribution systems, interior duct systems, fan integrated positive pressure dehumidified air ventilation in hot humid climates, quiet exhaust fan ventilation in cool climates, solar water heaters, heat pump water heaters, high efficiency right sized heating/cooling equipment, and gas fired combo space/water heating systems.

HOMES BY THE FLORIDA HOME ENERGY AND RESOURCES ORGANIZATION (FL.H.E.R.O.)

Over 400 single and multifamily homes have been constructed in the Gainesville, FL area with technical assistance from FL H.E.R.O. These homes were constructed by over a dozen different builders. In this paper data from 310 of these homes is presented. These homes have featured better envelopes and windows, interior and/or duct systems with adequate returns, fan integrated positive pressure dehumidified air ventilation, high efficiency right sized heating/cooling equipment, and gas fired combo space/water heating systems. The innovative outside air (OA) system is described below.

The OA duct is located in the back porch (Figure 1) or in the soffit (Figure 2). The OA is filtered through a 12"x12" filter (which is readily available) located in a grill (Figure 3) which is attached to the OA duct box. The flex OA duct size varies depending on the system size - 4" for up to 2.5 tons, 5" for 3 to 4 ton and 6" for a 5 ton system. The OA duct terminates in the return air plenum after a manually adjustable butterfly damper (Figure 4).

Figure 1 OA Intake Duct in Back Porch

Figure 2 OA Intake Duct in Soffit

Figure 3 Filter Backed Grill Covering the OA Intake

Figure 4 Butterfly Damper for OA control

The damper can be set during commissioning and closed by the homeowner in case the OA quality is poor (e.g. forest fire). This system introduces filtered and conditioned ventilation air only when the cooling or heating system is operational. The ventilation air also positively pressurizes the house. Data on the amount of ventilation air or positive pressurization is not available from a large sample of homes. A few measurements indicate that about 25 to 45 cfm of ventilation air is provided which pressurizes the house in the range of +0.2 to +0.4 pascals.

Measured Home Energy Ratings (HERS) and airtightness on these FL. H.E.R.O. homes is presented next in figures 5 through 8. Data is presented for both single family detached (SF) and multifamily homes (MF). See Table 2 below.

Table 2. Summary statistics on FL.H.E.R.O. Homes
n = sample size

	SF	MF
Median cond area	1,909	970
% constructed with 2x4 frame or frame and block	94%	100%
Avg. Conditioned Area, ft^2	1,993 (n=164)	1,184 (n=146)
Avg. HERS score	87.0 (n=164)	88.0 (n=146)
Avg. ACH50	4.5 (n=164)	5.2 (n=146)
Avg. Qtot (CFM25 as %of floor area)	6.9% (n=25)	5.0% (n=72)
Avg. Qout (CFM25 as %of floor area)	3.0% (n=15)	1.4% (n=4)

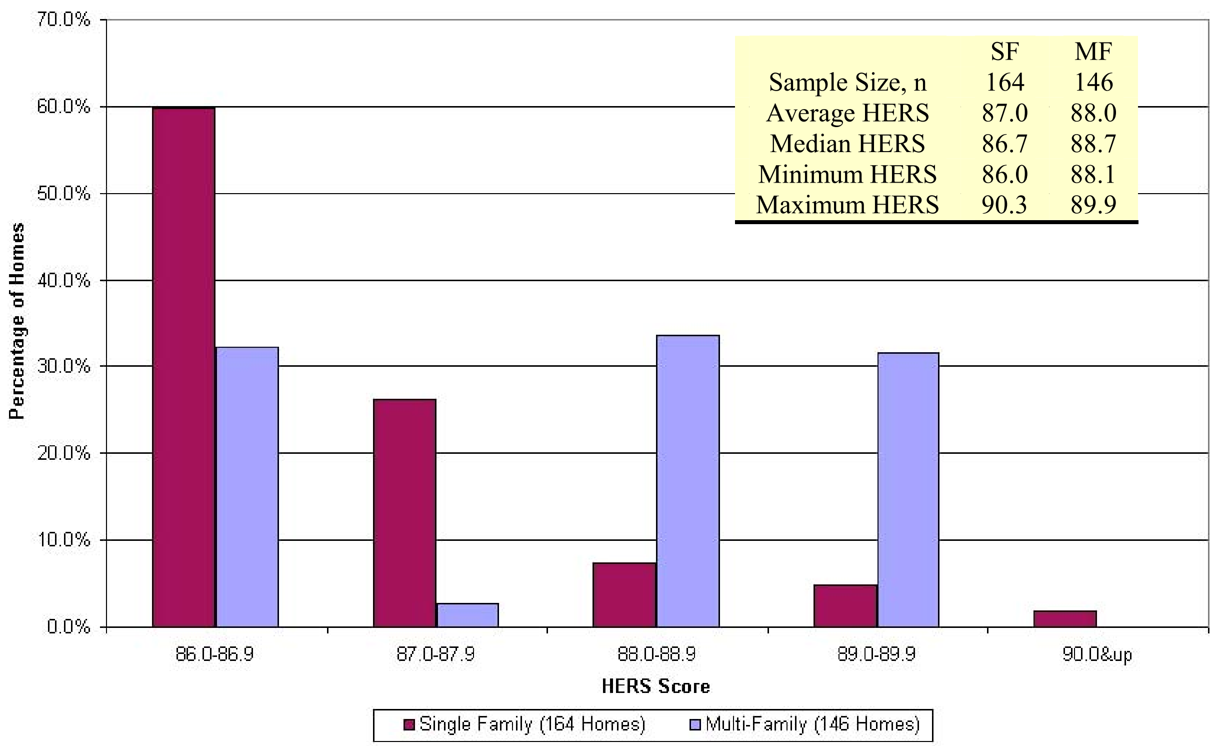

Figure 5 HERS Scores for FL H.E.R.O. Homes

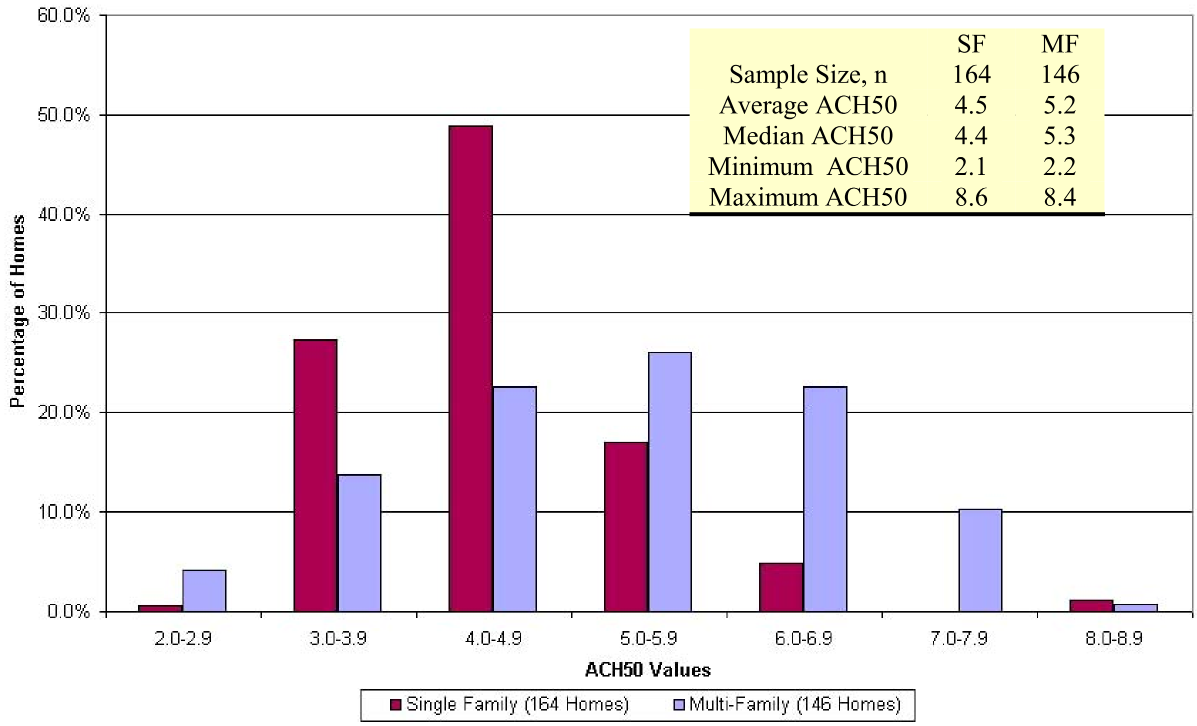

Figure 6 ACH50 Values for FL H.E.R.O. Homes

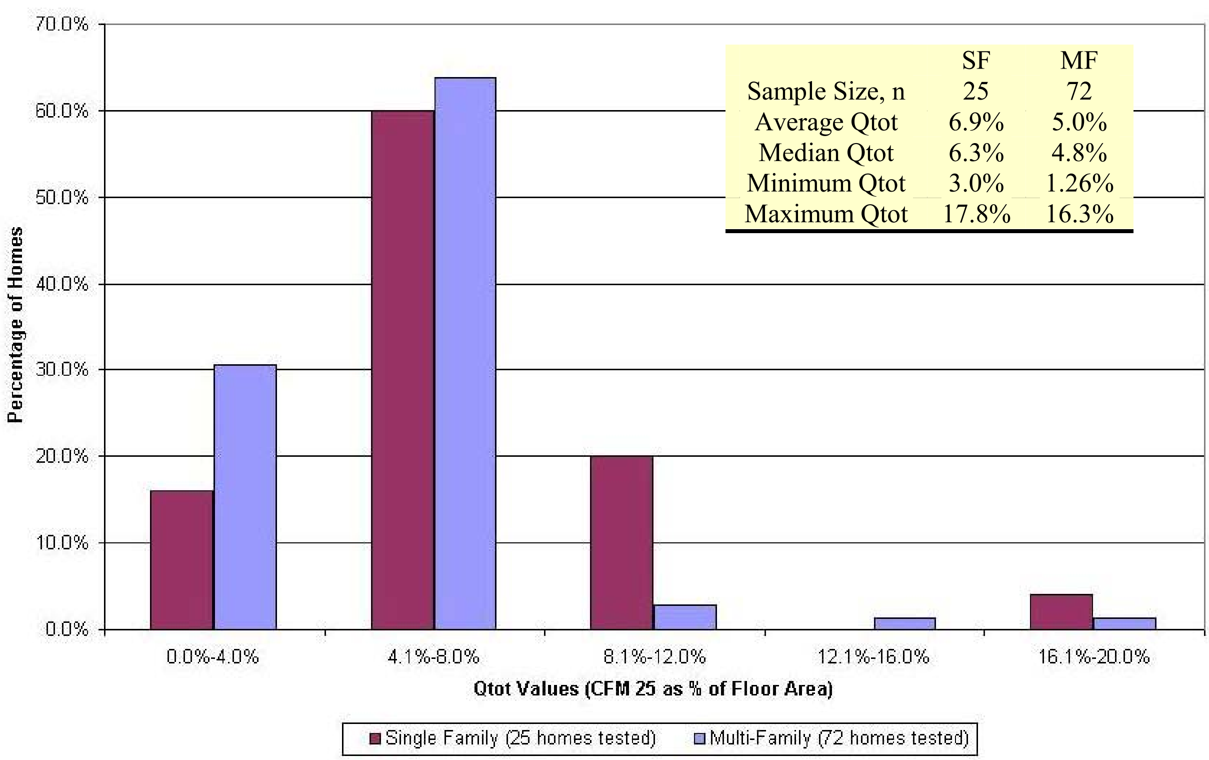

Figure 7 Qtot Values for FL H.E.R.O. Homes

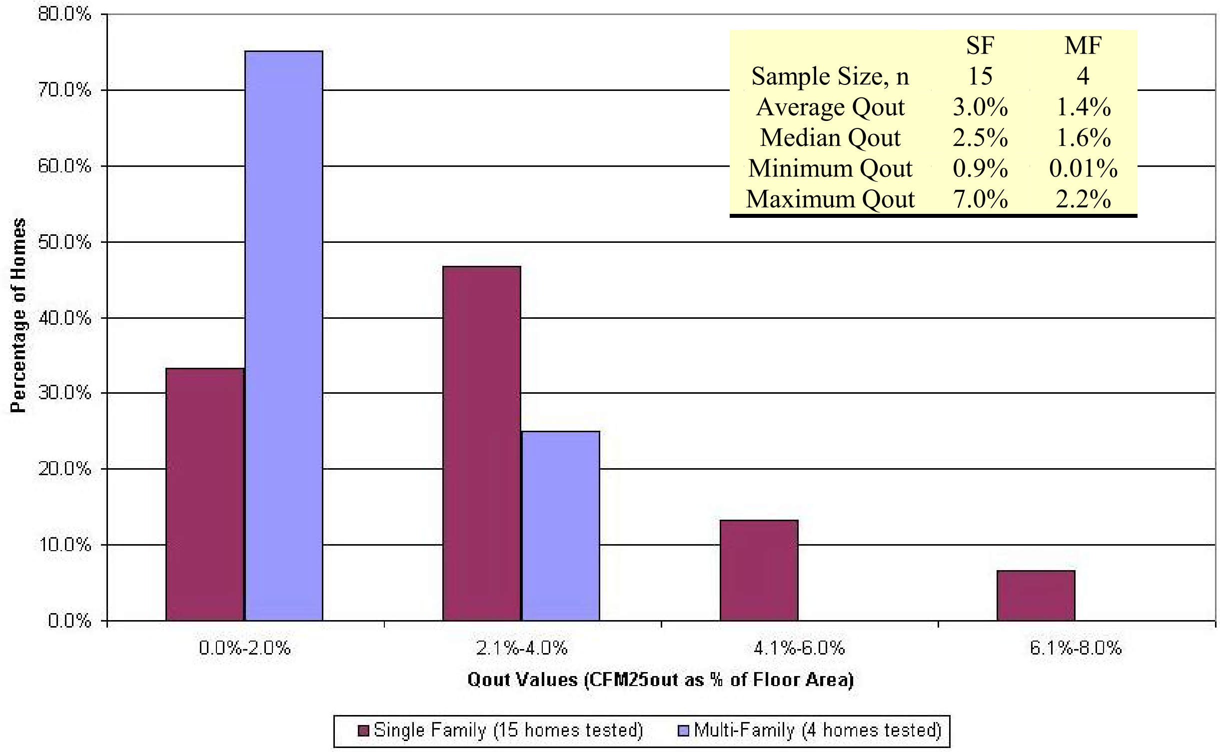

Figure 8 Qout Values for FL H.E.R.O. Homes

Data is available for other typical non BAIHP, new Florida homes (FPL , 1995 and Cummings et al, 2001). The FPL study had a sample size of over 300 single family homes and the median Qout was 7.5% , three times that of the FL. H.E.R.O. homes. In the Cummings study of 11 homes the measured average values were : ACH50= 5.7, Qtot=9.4% and Qout=4.7%. Although the sample sizes are small the FL. H.E.R.O. homes appear to have significantly more airtight duct systems than typical homes.

The remainder of the paper presents status of other tasks of the BAIHP project.

OTHER BAIHP TASKS

Moisture Problems in HUD code homes

The BAIHP team expends considerable effort working to solve moisture problems in existing manufactured homes in the hot, humid Southeast.

Some manufactured homes in Florida and the Gulfcoast have experienced soft walls, buckled floors, mold, water in light fixtures and related problems. According to the Manufactured Housing Research Alliance (MHRA), who we collaborate with, moisture problems are the highest priority research project for the industry.

The BAIHP team has conducted diagnostic tests (blower door, duct blaster, pressure mapping, moisture meter readings) on about 40 such problem homes from five manufacturers in the past two years and shared the results with MHRA. These homes were newly built (generally less than 3 years old) and in some cases just a few months old when the problems appeared. The most frequent causes were:

- Leaky supply ducts and/or inadequate return air pathways resulting in long term negative pressures.
- Inadequate moisture removal from oversized a/c systems and/or clogged condensate drain, and/or continuous running of the air handler fan.
- Presence of vinyl covered wallboard or flooring on which moist air condenses creating mold, buckling, soft walls etc.
- Low cooling thermostat set point (68-75F), below the ambient dew point.
- Tears in the belly board and/or poor site drainage and/or poor crawlspace ventilation creating high rates of moisture diffusion to the floor.

Note that these homes typically experience very high cooling bills as the homeowners try to compensate for the moisture problems by lowering the thermostat setpoints. These findings have been reported in a peer reviewed paper presented at the ASHRAE IAQ 2001. conference (Moyer et al)

The Good News:

As a result of our recommendations and hands-on training, BAIHP partner Palm Harbor Homes (PHH) has transformed duct design and construction practices in all of its 15 factories nationwide producing about 11,000 homes/yr. All Palm Harbor Home duct systems are now constructed with mastic to nearly eliminate air leakage and produced with return air pathways for a total cost of <$10/home!! The PHH factory in AL which had a high number of homes with moisture problems has not had a single problem home the past year!

Field Monitoring

Several houses and portable classrooms are being monitored and the data displayed on the web. (Visit http://www.infomonitors.com/). Of special interest is the side-by-side monitoring of two manufactured homes on the campus of the North Carolina A & T U. where the advanced home is saving about 70% in heating energy and nearly 40% in cooling energy, proving that the Building America goal can be met in manufactured housing. Other monitored sites include the Washington State U. Energy House in Olympia, WA; the Hoak residence in Orlando, FL; two portable classrooms in Marysville, WA; a classroom each in Boise, ID and Portland, OR. See other papers being presented at this symposium for details on two recently completed projects giving results from duct repairs in manufactured homes (Withers et al) and side by side monitoring of insulated concrete form and base case homes (Chasar et al).

"Cool" Roofs and Unvented Attics

Seven side-by-side Habitat homes in Ft. Myers, FL. were tested under unoccupied conditions to examine the effects of alternative roofing strategies. After normalizing the data to account for occupancy and minor differences in thermostat set points and equipment efficiencies, the sealed attic saved 9% and the white roofs saved about 20% cooling energy compared to the base case house with a dark shingle roof for the summer season in South Florida. Visit http://www.fsec.ucf.edu/%7Ebdac/pubs/coolroof/exsum.htm for more information.

Habitat for Humanity

Habitat for Humanity affiliates work in the local community to raise capital and recruit volunteers. The volunteers build affordable housing for and with buyers who can't qualify for conventional loans but do meet certain income guidelines. For some affiliates, reducing utility costs has become part of the affordability definition.

To help affiliates make decisions about what will be cost effective for their climate, BAIHP researchers have developed examples of Energy Star homes for more than a dozen different locations. These are available on the web at http://www.fsec.ucf.edu/bldg/baihp/casestud/hfh_estar/index.htm . The characteristics of the homes were developed in conjunction with Habitat for Humanity International (HFHI), as well as Executive Directors and Construction Managers from many affiliates. Work is continuing with HFHI to respond to affiliates requesting a home energy rating through an Energy and Environmental Practices Survey. 36 affiliates have been contacted and home energy ratings are being arranged using combinations of local raters, Building America staff, and HFHI staff.

HFHI has posted the examples of Energy Star Habitat homes on the internal web site PartnerNet which is available to affiliates nationwide.

"Green" Housing

A point based standard for constructing green homes in Florida has been developed and may be viewed at http://www.floridagreenbuildings.org/. The first community of 270 homes incorporating these principles is now under construction in Gainesville, FL. The first home constructed and certified according to these standards has won an NAHB energy award.

BAIHP researchers are participating as building science - sustainable products advisor to the HUD Hope VI project in Miami, redeveloping an inner city area with over 500 units of new affordable and energy efficient housing.

Healthy Housing

BAIHP researchers are participating in the development of national technical and program standards for healthy housing being developed by the American Lung Association.

A 50-year-old house in Orlando is being remodeled to include energy efficient and healthy features as a demonstration project.

EnergyGauge USA®

This FSEC developed software uses the hourly DOE 2.1E engine with FSEC enhancements and a user-friendly front end to accurately calculate home energy ratings and energy performance. This software is now available. Please visit http://energygauge.com/ for more information.

Industrial Engineering Applications

The UCF Industrial Engineering (UCFIE) team supported the development and ongoing research of the Quality Modular Building Task Force organized by the Hickory consortium, which includes thirteen of the nation's largest modular homebuilders. UCFIE led in research efforts involving factory design, quality systems and set & finish processes. UCFIE used research findings to assist in the analysis and design of two new modular housing factories – Excel homes, Liverpool, PA and Cardinal Homes - Wyliesburg, VA.

CONCLUSIONS

The entire BAIHP team of over 20 researchers and students are involved in a wide variety of activities to enhance the energy efficiency, indoor air quality and durability of new housing and portable classrooms.

In addition to energy efficiency, durability, health, comfort and safety BAIHP builders typically consider resource and water efficiency. For example, in Gainesville, FL BAIHP builders have incorporated the following features in developments:

- Better planned communities
- More attention given to preserving the natural environment
- Use of reclaimed sewage water for landscaping
- Use of native plants that require less water
- Storm water percolating basins to recharge the ground water
- Designated recreational areas
- Better designed and built infrastructure
- Energy efficient direct vented gas fireplaces (not smoke producing wood)

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Special thanks to Bert Kessler of Palm Harbor Homes, Mike Dalton of Stylecrest Sales, Mike Wade of Southern Energy Homes and David Hoak of Alten Design for the hundreds of hours they have each contributed to the success of BAIHP.

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