Influence of Attic Radiant Barrier Systems on Air Conditioning Demand in an Utility Pilot Project

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Abstract

A utility monitoring project has evaluated radiant barrier systems (RBS) as a new potential demand site management (DSM) program. The study examined how the retrofit of attic radiant barriers can be expected to alter utility residential space conditioning loads. An RBS consists of a layer of aluminum foil fastened to roof decking or roof trusses to block radiant heat transfer between the hot roof surface and the attic below. The radiant barrier can significantly lower summer heat transfer to the attic insulation and to the cooling duct system. Both of these mechanisms have strong potential impacts on cooling energy use as illustrated in Figures 1 and 2.

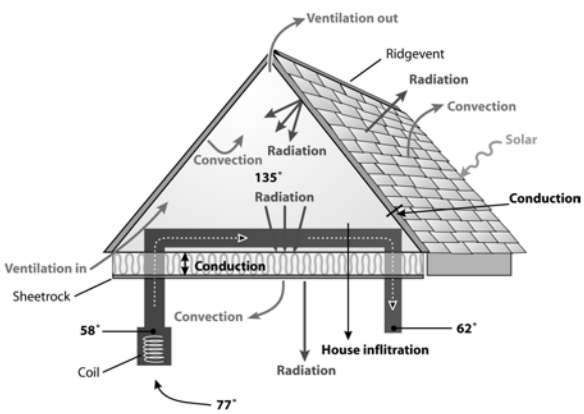


Figure 1. Heat transfer mechanisms for standard vented attic

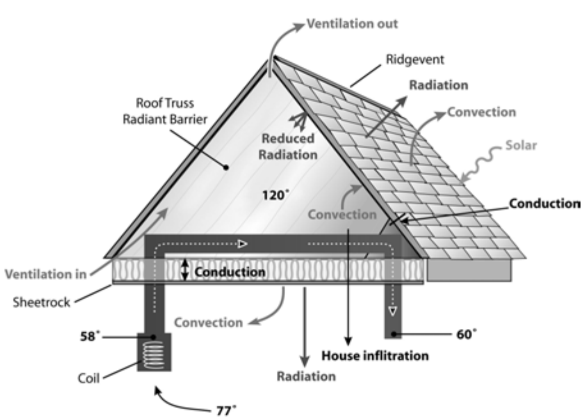


Figure 2. Altered attic heat transfer mechanisms due to RBS.

The pilot project involved installation of RBS in nine homes that had been extensively monitored over the preceding year. The houses varied in conditioned floor area from 939 to 2,440 square feet; attic insulation varied from R-9 to R-30. The homes had shingle roofs with varying degrees of attic ventilation. The radiant barriers were installed during the summer of 2000. Data analysis on the pre and post cooling and heating consumption was used to determine impacts on energy use and peak demand for the utility.

The average cooling energy savings from the RBS retrofit was 3.6 kWh/day, or about 9%. The average reduction in summer afternoon peak demand was 420 watts (or about 16%).

Introduction

An attic radiant barrier system (RBS) consists of a layer of aluminum foil placed in an air space to block radiant heat transfer between the roof surface and the attic insulation below. An RBS depends on the surface property of low infrared emissivity to provide the performance benefit. RBS is a mature energy-saving technology having first been evaluated in the late 1950s (Joy, 1958). Most innovations now are materials related. For instance, industry has recently begun to manufacture roof plywood decking with the RBS already adhered to its underside. Probably the greatest potential for performance enhancement comes from proper installation. Roof mounted application is preferred over horizontal application; the later will significantly degrade in performance from eventual dust accumulation (Fairey and Beal, 1988; Levins et al., 1990).

Performance Data from Previous Investigations

Radiant barriers are a well documented means to reduce the rate of heat transfer through the ceiling of residential buildings (Fairey et al., 1988). For instance, field measurement of the retrofit of ceiling insulation from R-11 to R-30 in a test home in Tennessee showed a 16% drop in the measured cooling energy use (Levins and Karnitz, 1987). Addition of RBS in these tests also showed a similar level of cooling energy savings to that of R-30 insulation (16% savings). However, these measurements were made in a home with the air distribution system in the crawlspace. Larger savings from the RBS might be expected were the ducts located in the attic, which is common in homes with slab on grade construction (Parker et al., 1991; Medina, 1994). Generally, previous research in the Southeast has shown that roof mounted radiant barriers can reduce ceiling heat flux by 25 - 50% with annual cooling electricity savings of 7 - 10% (Fairey et al., 1988, 1989; Wilkes, 1991; Ober, 1991; Ashley et al., 1994; Parker and Sherwin, 1998). Reduction of peak cooling loads is generally higher. Added attic ventilation with radiant barriers substantially improve performance since otherwise convected heat to the attic is removed by ridge vents (Joy, 1958; Parker and Sherwin, 1998).

Although isolated field studies abound, the performance of radiant barriers as an effective cooling demand reduction measure remains largely un-utilized within utility programs for existing homes. Evaluation of an installed RBS system in a home in South Florida showed a reduction in measured space cooling of 5.5% (Parker et al., 1997), although savings were marred by a daytime thermostat setup. Careful testing of two unoccupied side-by-side centrally air conditioned homes in Gainesville Florida showed an 8% reduction in peak day air conditioning with R-19 ceiling insulation (Fairey et al., 1988).

Attic geometry can exact limitations to homes that can use the technology for retrofit. The requirement to have an air space for adequate radiant barrier performance and the need for access will limit the ability to use RBS for homes with very low slope roofs (poor access) and for those with cathedral ceilings. In homes with very poor attic access, additional labor costs may make such applications economically unattractive. Also, test data shows that homes with composition shingles reach the greatest temperatures; tile roofs experience less attic heating and thus would likely produce less benefits from an RBS (Beal and Chandra, 1995; Parker and Sherwin, 1998). In the utility statistical sample, some 17 homes or 10% had tile roofs. Finally homes with moderate to extensive roof shading would not likely benefit from RBS installation. In the base sample, some 54 homes or 32%, had roof shading (Parker et al., 2000). Thus, based on the aforementioned factors, perhaps half of existing homes in the Central Florida area could feasibly have an RBS installed.

RBS Pilot Project

In spring 2000, Utility recruited homes for the RBS pilot project from the existing list of Central Florida homeowners that were participating in its residential monitoring project. Qualifying homes had to have asphalt shingle roofs which are not shaded by surrounding landscape and have some attic access. As typical of homes in Central Florida, all of the test sites had attic located duct systems which were either all R-6 flex duct or a combination of R-4 duct-board and R-4 to R-6 flex. Ducts systems may have important interactions with radiant barriers since reduction to attic heat load can reduce heat gain to the cooling duct system (Hageman and Modera, 1996). None of the homes had whole house fans or attic exhaust fans although a number had attic power ventilators. These operate by a thermostat to come on at approximately 105°F and draw about 200 W each.

A total of nine homes were selected for the project and had radiant barriers installed during the summer of 2000. The RBS system used was a multi-layer foil faced material manufactured by the *Fi-Foil Company* in Audurndale, FL. The material has a tested long-wave emittance of 0.03 - 0.05. The first RBS was installed on June 22nd and the last was installed on September 16th. The houses varied in conditioned floor area from 939 to 2,440 square feet. Attic insulation varied from R-9 to R-30.

Analysis Methods

We have evaluated the savings for each individual installation using a matched weather data comparison. The analysis of the period post RBS installation in 2000 was matched with similar time periods during 1999 with nearly identical average outdoor temperatures. This method has the advantage of using long-term weather periods. Its disadvantage is that any changes in thermostat setting or lifestyle over the year will be included in the results.

Site #199

The first test site (#199) was a 2200 square foot home built in 1980 and located in Largo, Florida. It was occupied by a family of three. The roof has a 5/12 pitch with dark brown shingle. Since dark brown shingles have been shown to have a solar absorptance of greater than 90% (Parker et al., 2000), there is considerable potential for producing high attic temperatures during summer months.

Cooling is provided by a 2.5-ton heat pump with an attic mounted air handler unit (AHU). The RBS was installed on June 22, 2000. The home has R-19 ceiling insulation under a brown asphalt shingle roof. The attic air handler could be expected to influence results since any return leakage into the cabinet or heat transfer to the evaporator section would be influenced by the prevailing attic thermal conditions (Figure 3).

Figure 3. Site #199 showing attic air handler prior to retrofit.

Prior to the RBS installation, the site had a measured space cooling consumption of 9,189 kWh (4.19 kWh/ft^2) in 1999 (compared with a system-wide average of 5,646 kWh). The site had very little recorded consumption for space heating – only 68 kWh in 1999 – largely due to the occupants being willing to tolerate low interior temperatures without heating. Figure 4 show the attic after the RBS was installed on June 22, 2000. As shown by the attic temperature history, the peak summer attic temperatures were reduced by about 15^{o}F (Figure 5).

Figure4. Site #199 after RBS retrofit

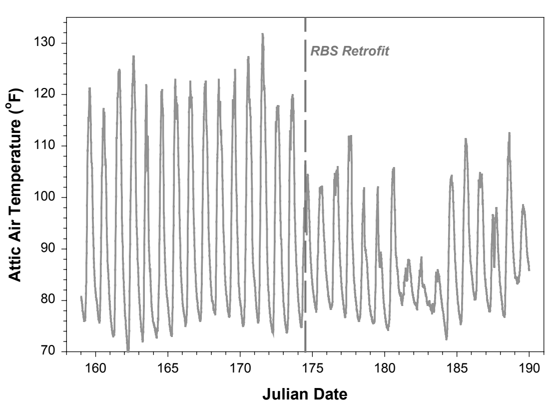


Figure 5. Site #199 attic temperature history before and after retrofit on June 22, 2000 (Julian day 174).

Using periods with very similar average temperatures in 1999 and 2000, the RBS showed a reduction in cooling energy use of 19.7% (10.6 kWh/day). The average daily peak attic air temperature was reduced by 12.2^{o}F. The reduction in peak cooling demand was 19% or 1.10 kW.

After installation, the occupants mentioned that interior comfort had been considerably improved which may have lead to a change in thermostat preference. The alteration of the load profile is shown in Figure 6.

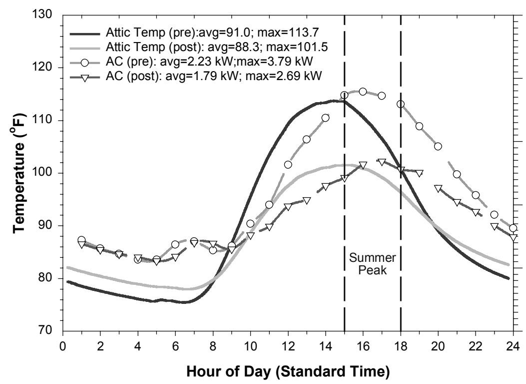


Figure 6. Site #199 RBS retrofit impact on attic air temperatures and AC cooling demand.

<u>Site #107</u>

The second RBS retrofit site was a 1,520 square foot home built in 1979 and located in New Port Richey. It was occupied by a single, middle aged woman; her preferred summer and winter temperatures were 78 and 65^{o}F, respectively. The 3/12 pitch roof also has medium gray composition shingles with the air handler located in the attic. There is no appreciable landscape shading although the home has two turbine attic vents. As with the first site, the attic location of the air handler was expected to yield additional savings. The home is conditioned by a 2.5-ton air conditioner with 10 kW of electric resistance strip heat. The ceiling insulation at this site is poor (R-12) as evidenced by the low insulation thickness. Measured annual space cooling in 1999 was 4,293 kWh (2.83 kWh/ft^2); space heating in the same year totaled 1,200 kWh (0.79 kWh/ft^2). The RBS was installed on June 26th, 2000. The attic temperature history is shown in Figure 7.

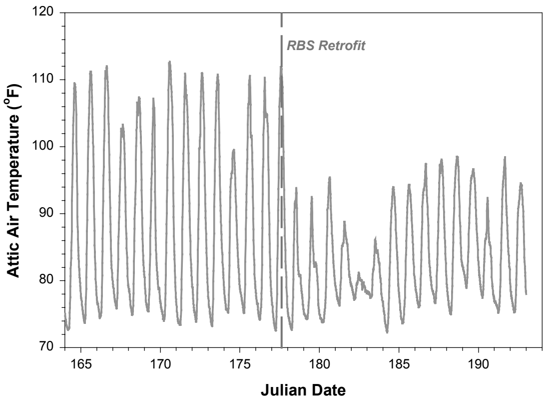


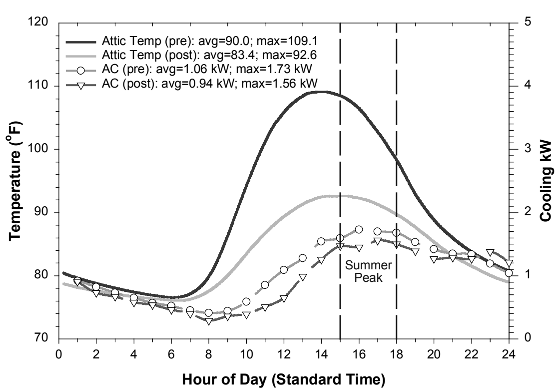
Figure 7. Site #107 attic temperature history before and after retrofit on June 26, 2000 (Julian day 178).

Using periods with very similar average temperatures in 1999 and 2000, the RBS showed a reduction in cooling energy use of 11.3% (2.9 kWh/day). The peak attic air temperature was reduced by 16.5°F. The reduction in peak cooling demand was 10% or 0.17 kW. The alteration of the load profile is shown in Figure 8.

Figure 8. Site #107 RBS retrofit impact on attic air temperatures and AC cooling demand.

Site 147

The third RBS retrofit site was a newer 1,520 square foot home built in 1989 and located in Tarpon Springs. It was occupied by an older couple who profess a preference for warmer temperatures in summer. The 5/12 pitch roof also has dark brown composition shingles with the air handler located in the attic. There is appreciable tree shading of the southeast and north-west exposures. As with other such sites, we would be expect the attic air handler location to yield additional savings. However, the ceiling insulation at this site consists of thick un-faced fiberglass batts (R-30).



The home is conditioned by a 2.5-ton heat pump with 5 kW of supplemental strip heat. Measured annual space cooling in 1999 was 2,475 kWh (1.63 kWh/ft^2); space heating in the same year totaled 476 kWh (0.31 kWh/ft^2). The RBS was installed on July 20th, 2000. The attic temperature history is shown in Figure 9.

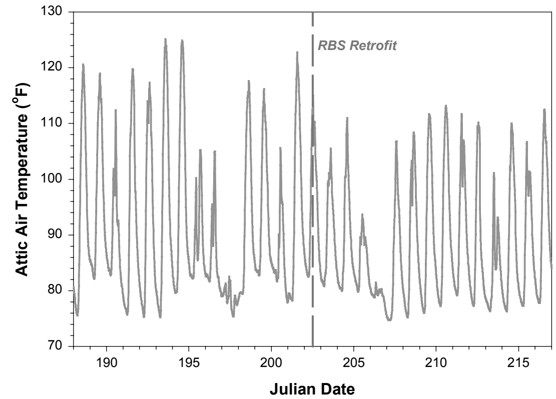


Figure 9. Site #147 attic temperature history before and after retrofit on July 20, 2000 (Julian day 202).

Using periods with very similar average temperatures in 1999 and 2000, the RBS showed a reduction in cooling energy use of 16.0% (2.6 kWh/day). The peak attic air temperature was reduced by 21.5°F. The reduction in peak cooling demand was 24.8% or 0.36 kW. The alteration of the load profile and attic temperatures is shown in Figure 10. The long-term time periods extend from July 21 - September 30 of 1999 and July 21 - September 30 of 2000.

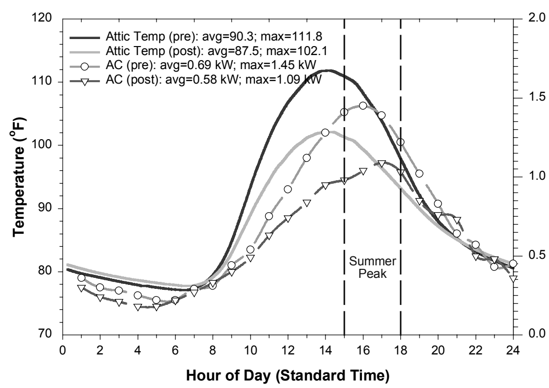


Figure 10. Site #147 RBS retrofit impact on attic air temperatures and AC cooling demand.

Site 72

The fourth RBS retrofit site was a newer 2,140 square foot home built in 1994 and located in Orlando. It was occupied by a family of three who like to maintain 77°F in summer and only infrequently use their heating system. The 6/12 pitch roof also has dark brown composition shingles. Unlike the previous sites, the air handler is not located in the attic, but in the garage. With the large roof pitch, the attic has a large volume; it is also forced ventilated by a four power ventilators which typically activate when the attic reaches 105°F. There is a small amount of tree shading of the southern and northern exposures. However, the ceiling insulation at this site appeared excellent on inspection; it consists of very thick and uniform blown fiberglass (R-30) as shown in Figure 11. The ducts are largely buried in the insulation. Along with the non-attic air handler, large attic volume and ventilation and good ceiling insulation, this should lead to relatively less impact from the radiant barrier. The home is conditioned by a 4-ton heat pump with 5 kW of supplemental strip heat. Measured annual space cooling in 1999 was 6,283 kWh (2.94 kWh/ft^2); space heating in the same year totaled 650 kWh (0.30 kWh/ft^2). The RBS was installed on July 21th, 2000. The attic temperature history is shown in Figure 12.

Figure 11. Excellent R-30 ceiling insulation at Site #72.

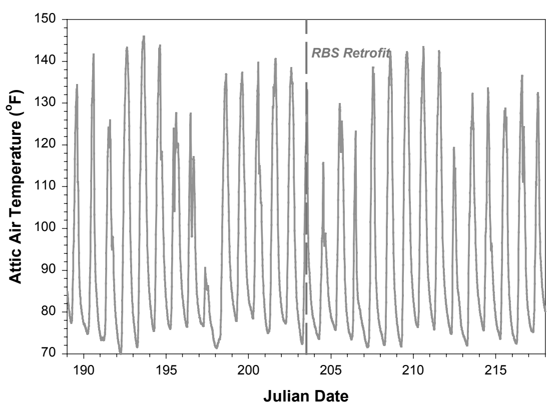


Figure 12. Site #72 attic temperature history before and after retrofit on July 21, 2000 (Julian day 203).

Using identical time periods with very similar average outdoor temperatures in 1999 and 2000, the RBS showed no reduction or real change in cooling energy use. The peak attic air temperature was reduced by 3.1^{o}F – only a slight drop. There was also no reduction to peak cooling demand, which increased insignificantly by 0.07 kW (Figure 13).

The lack of savings at Site #72 was largely due to a 1^{o}F lower thermostat set temperature in the post period data taken a year later. This is clearly illustrated by the averages plotted in Figure 14.

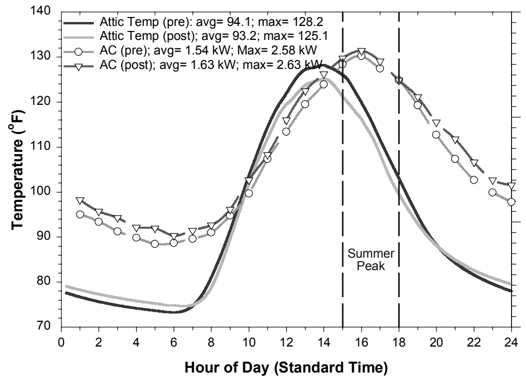


Figure 13. Site #72 RBS retrofit impact on attic air temperatures and AC cooling demand.

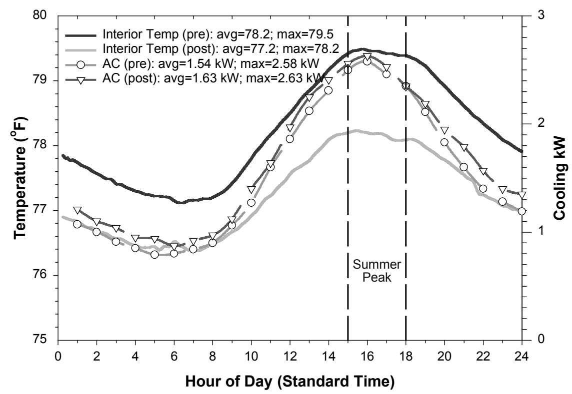


Figure 14. One degree lower interior set point maintained after RBS retrofit at Site #72 erased potential savings.

However, this site was incorporated into the overall project results, since thermostat "take back" reflects real world variation in customer behavior associated with residential DSM programs.

<u>Site 126</u>

The fifth RBS retrofit site was a 2,440 square foot home built in 1987 and located in Orlando. It was occupied by an older couple who profess a preference for cooler temperatures in summer. They indicate they leave the thermostat set to 73^{o}F year round. The 4/12 pitch roof has gray composition shingles. The air handler is located on the home interior. There is little landscape shading of the property. The ceiling insulation consists of blown fiberglass (R-19) as shown in Figure 15 but is not evenly distributed. The home is conditioned by a 3-ton air conditioner with natural gas heating. Likely due to the low temperature preference, measured annual space cooling in 1999 was high: 10,787 kWh (4.42 kWh/ft^2); space heating electrical use for the furnace air handler in the same year was 370 kWh (0.15 kWh/ft^2).[1] The RBS was installed on July 28th,

4 This level of space cooling is almost twice the average measured in the monitoring project (5,650 kWh). The site would be an excellent candidate for conversion to a high efficiency heat pump.

2000. The attic temperature history is shown in Figure 16.

Figure 15. Uneven R-19 ceiling insulation at Site #126.

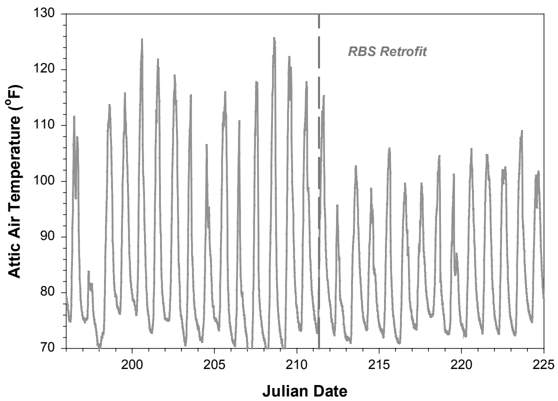


Figure 16. Site #126 attic temperature history before and after retrofit on July 28, 2000 (Julian day 210).

Using identical time periods with very similar average temperatures in 1999 and 2000, the RBS retrofit showed a large reduction in cooling energy use of 27.2% (17.8 kWh/day). The peak attic air temperature was reduced by 15.6°F. The reduction in peak cooling demand was 26.6% or 1.11 kW. Examination of interior temperatures maintained from one year to the next showed that part of the reduction was due to a slightly elevated interior temperature in the post period. We speculate that the large savings are due to the relatively poor quality of the ceiling insulation and the change in thermostat setting. The load profile and attic temperatures are shown in Figure 17.

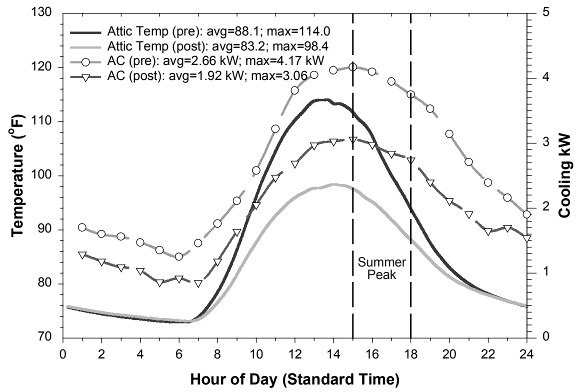


Figure 17. Site #126 RBS retrofit impact on attic air temperatures and AC cooling demand.

Site #10

The sixth RBS retrofit site was a 1,840 square foot home built in 1984 and located in Apopka. It was occupied by an older couple who prefer 77°F in summer and 71°F in winter. The 4/12 pitch roof has dark brown composition shingles. The air handler is located in the garage. However, there is some tree shading of the property including portions of the roof which could be expected to reduce the savings of the RBS. The attic is also well vented with continuous soffit, ridge vents and temperature controlled power vents. The ceiling insulation consists of 10-inch fiberglass batts (R-30), but is not evenly distributed. The home is conditioned by a 3-ton heat pump with 5 kW of supplemental strip heat. Annual space cooling in 1999 was 8,263 kWh (4.48 kWh/ft^2); space heating in the same year was 1,603 kWh (0.87 kWh/ft^2). The RBS was installed on August 4th, 2000. The attic temperature history is shown in Figure 18.

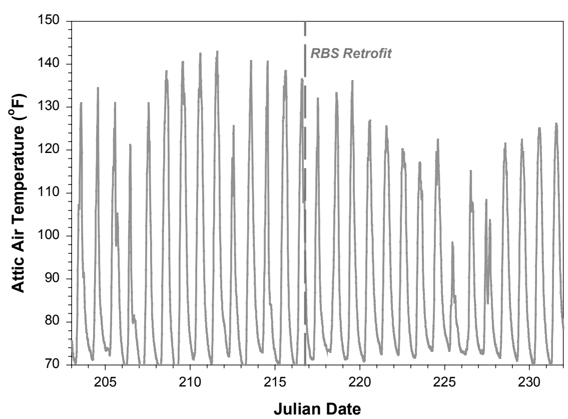


Figure 18. Site #10 attic temperature history before and after retrofit on August 4, 2000 (Julian day 217).

Using identical time periods with similar average temperatures in 1999 and 2000, the RBS showed a reduction in cooling energy use of 5.3% (2.4 kWh/day). The peak attic air temperature was reduced by 11.4°F. The reduction in peak cooling demand was 10.8% or 0.30 kW. The alteration of the load profile and attic temperatures is shown in Figure 19.

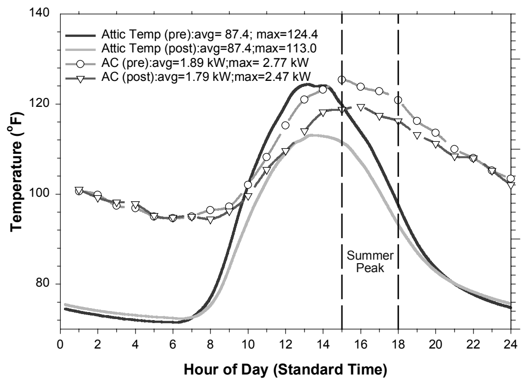


Figure 19. Site #10 RBS retrofit impact on attic air temperatures and AC cooling demand.

Site #155

The seventh RBS retrofit site was a small 939 square foot home built in 1975 and located in Orlando. It is occupied by two adults who prefer 72°F in during the day and 78°F at night. They indicate a preference for 72°F in winter. The 4/12 pitch roof has light gray composition shingles. The air handler is located in the interior. However, there is some tree shading of the property including portions of the roof which could be expected to reduce savings. The attic is also well vented with continuous soffit, turbine vents and temperature controlled power vents. The ceiling insulation is poor, consisting of 3-inches of blown (R-9) which is unevenly distributed. Several voids were noted in the audit. The home is conditioned by a 2-ton air conditioner. It is heated by 10 kW of electric resistance strip heat. Annual space cooling in 1999 was 4,420 kWh (4.71 kWh/ft^2); space heating in the same year was 810 kWh (0.86 kWh/ft^2). The RBS was installed on August 31st, 2000. The attic temperature is shown in Figure 20.

This site, along with the remaining two, had savings which were influenced by the late time in the season in which the RBS was installed. Even so, using identical time periods with similar average temperatures in 1999 and 2000, the RBS showed a reduction in cooling energy use of 8.4% (1.7 kWh/day). The peak attic air temperature was reduced by 3.0°F. The reduction in peak cooling demand was 8.5% or 0.14 kW. The alteration of the load profile and attic temperatures is shown in Figure 21.

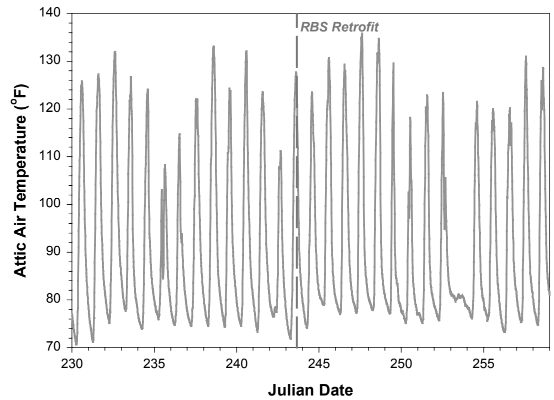


Figure 20. Site #155 attic temperature history before and after retrofit on August 31, 2000 (Julian day 244). Note minimal change to attic temperatures.

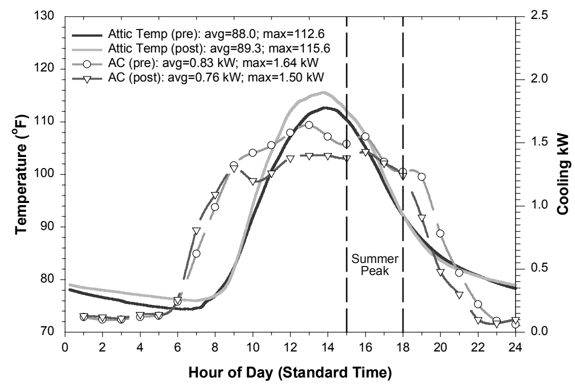


Figure 21. Site #155 RBS retrofit impact on attic air temperatures and AC cooling demand.

Site #88

The eighth RBS retrofit site was a 2,115 square foot home built in 1989 and located in Winter Springs. It was occupied by two adults who prefer it very cool in summer (70°F) and claim to heat sparingly. The 4/12 pitch roof has medium gray composition shingles. The air handler is located in the attic. There is little tree shading of the property. The very dark roof and attic air handler could be expected to increase RBS savings. The attic is also well vented with continuous soffit, turbine vents and temperature controlled power vents. The ceiling insulation is typical, consisting of 6-inches of blown fiberglass (R-19) although unevenly distributed. The home is conditioned by a 3.5-ton heat pump with 10 kW of supplemental strip heat. Annual space cooling in 1999 was 7,817 kWh (3.70 kWh/ft^2); space heating in the same year was 313 kWh (1.57 kWh/ft^2). Space heat was elevated since the heat pump was not functioning in heating mode and operated exclusively with the heat pump's supplemental 10 kW strip heat. The RBS was installed on September 7th, 2000. The attic temperature history pre and post retrofit is shown in Figure 22.

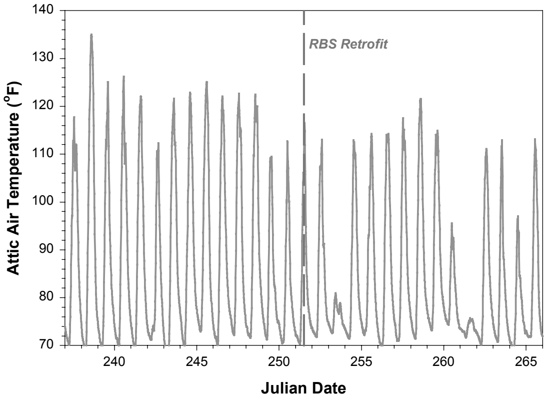


Figure 22. Site #88 attic temperature history before and after retrofit on September 7, 2000 (Julian day 251).

This site had savings which were influenced by the late time in the season in which the RBS was installed. The late installation also considerably limited the available period of comparison to only the last three weeks of September in 2000. However larger than the influence of the RBS was the fact that the household reduced their cooling thermostat set temperature one week after the installation of the RBS by approximately 2°F. This more than negated any potential savings (and may be considered another case of "take-back").

Nonetheless, since the idea within the pilot project was to consider "real world" performance it was included in the analysis. Using identical time periods with similar average outdoor temperatures in 1999 and 2000, the post RBS retrofit showed an *increase* in cooling energy use of 8.4% (1.7 kWh/day). There was also little observed impact on the peak attic air temperature. The reduction in peak cooling demand was 8.5% or 0.14 kW. The alteration of the load profile and attic temperatures is shown in Figure 23.

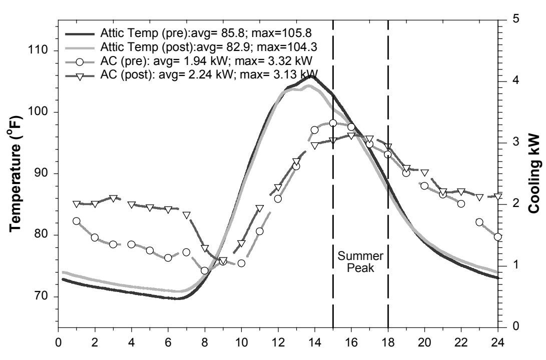


Figure 23. Site #88 RBS retrofit impact on attic air temperatures and AC cooling demand. Note absence of saving largely due to thermostat "take back".

Site #180

The ninth and final RBS retrofit site was a 1,790 square foot home built in 1991 and located in Orlando. It was occupied by a family of three. The household prefer 78°F in during the summer. They indicate a preference for 70°F on winter nights and 67 otherwise. The 4/12 pitch roof has dark gray composition shingles. The air handler is located in the interior. The attic is typically vented with continuous soffit and three off-ridge bents. The ceiling insulation is good, consists of 6-inches of blown fiberglass (R-19) which is very evenly distributed. The home is conditioned by a 3-ton heat pump with 5 kW of supplemental strip heat. Annual space cooling in 1999 was 5,903 kWh (3.30 kWh/ft^2); space heating in the same year was 737 kWh (0.41 kWh/ft^2). The RBS was installed on September 16th, 2000. The attic temperature history is shown in Figure 24.

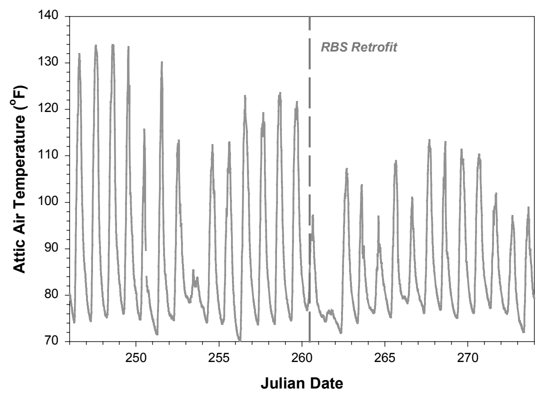


Figure 24. Site #180 attic temperature history before and after retrofit on September 16, 2000 (Julian day 260).

This site observed savings were likely influenced by the late time in the season in which the RBS was installed. Using identical time periods with similar average temperatures in 1999 and 2000, the RBS showed no reduction in cooling energy use. Part of this may be to a lower interior temperature during nighttime hours during the post period. Cooling use *increased* by of 4.5% (1.4 kWh/day). However, the peak attic air temperature was reduced by 3.9°F. The reduction in peak cooling demand was negligible and within the error limit of estimation: 1.4% or 0.02 kW. The alteration of the load profile and attic temperatures is shown in Figure 25.

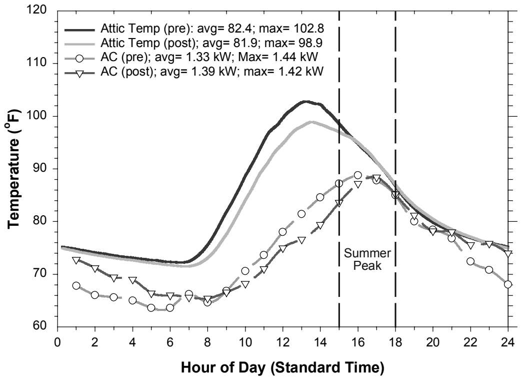


Figure 25. Site #180 RBS retrofit impact on attic air temperatures and AC cooling demand. Short monitoring period likely influences results in a negative fashion.

Overall Results

Savings ranged from a high of 27% (Site #126) to negative savings ("take back") at Site #88. The highest savings came from RBS installations with attic air handlers. There were also no indicated savings at Site #180 due to problems with the analysis from the late RBS installation. Based on the performance at the individual sites, we performed an overall evaluation of the savings from the radiant barrier systems installed during the summer. This was done by preparing a composite load profile for the average of all eight sites shown in Figure 26. We excluded Site #180 since it would have likely yielded a cooling energy reduction had the RBS retrofits been performed earlier in the summer.

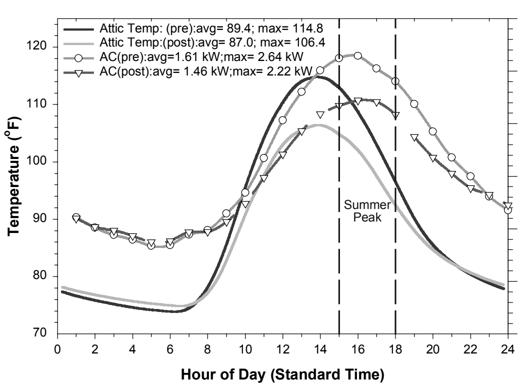


Figure 26. Composite profiles of RBS impact on summer attic air temperatures and AC demand in eight monitored sites. Pre-data from summer 1999; post from summer 2000 after installation.

The average cooling energy savings amounted to 3.6 kWh/day (9.3%). The mean reduction in peak demand was 420 watts (or about 16.0%). The aggregate load profile for all eight evaluated sites pre and post RBS installation is shown in Figure 27. There was an average 8.4^{o} drop in the peak daily summer attic temperature. Note that loads are slightly increased at night (an RBS does not allow the attic to cool off as readily as without due to inhibition of night sky radiation), but reductions are strongly concentrated during the utility summer peak demand period.

Figure 27 compares the excellent outdoor temperature match between the composite analysis for the pre RBS and post RBS periods. The second plot on the graph shows the improved indoor temperature condition post retrofit as well as some evidence at night of slightly lower thermostat set points.

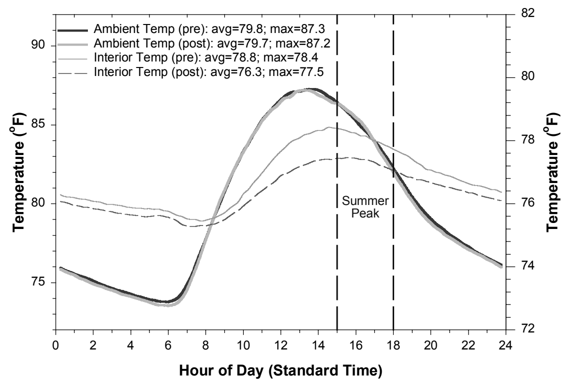


Figure 27. Comparison of average outdoor and indoor temperature profiles match in the pre and post period.

Comparison with Added Ceiling Insulation

The utility data also indicate larger summer peak reductions from the RBS than from added insulation. As shown in Figure 28, changing from R-19 to R-30 produces an average daily cooling load reduction of 3.4 kWh – just slightly lower than the average energy savings produced by the RBS. However, the demand reduction from the RBS (Figure 26) are concentrated during the summer utility peak period.

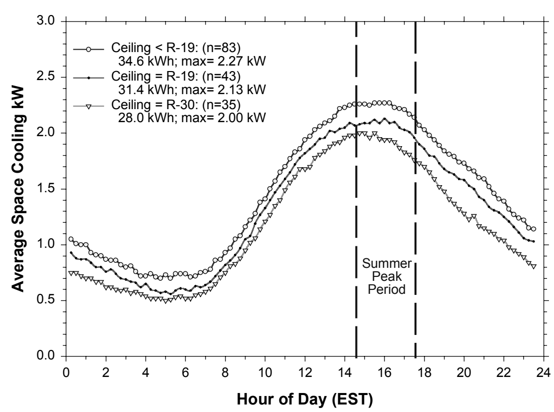


Figure 28. Impact of ceiling insulation on summer cooling demand in the utility monitoring sites (June 21-Sept. 30, 1999).

The average peak reduction from the RBS (420 Watts) was three times a great as that produced by added insulation. That data showed that R-30 (n=35) vs. R-19 (n= 43) insulation produced a 3.4 kWh/day savings (11%) with a peak demand reduction of 130 Watts (6%). We speculate the higher peak savings from the RBS was due to reduced heat gains to the attic duct system and also because radiation potential between roof and attic is greatest during peak cooling demand periods.

Winter Performance

RBS mainly impact cooling, but should produce some beneficial peak heating demand reduction. This happens since the RBS retards the rate at which the roof radiates heat to the night sky and results in warmer attic temperatures during the night hours and during the critical morning winter peak period. Slightly lower mid-day attic temperatures will be produced by the RBS. However, most heating in Central Florida takes place during the early morning and during the evening and not during the middle of the day when the RBS reduces attic temperatures. In previous work a detailed simulation analysis by Oak Ridge National Laboratory showed space heating reductions in Miami, Orlando and Atlanta (Wilkes, 1991). Also, detailed measurements by ORNL showed heating demand and energy reductions in monitored Tennessee homes (Levins and Karnitz, 1987).

We performed a rough comparison by comparing two winter days pre and post RBS installation that had similar minimum temperatures during the peak morning period. Figure 29 shows the comparative outdoor temperatures on the two days.

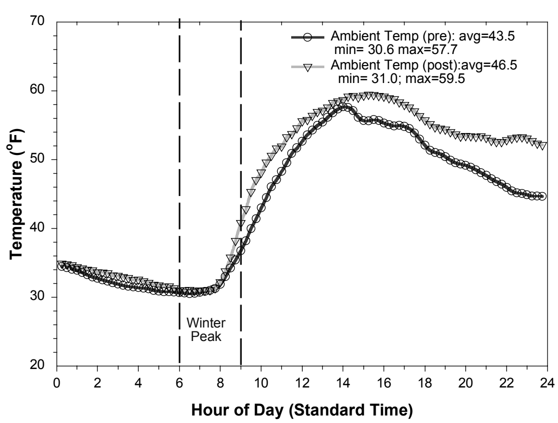


Figure 29. Match of outdoor temperature on winter comparison days. Pre: January 6, 1999; Post: January 6, 2001. Note correspondence during peak.

The lower total daily space heating energy use with the RBS is not meaningful due to differences in the afternoon outdoor temperatures. However, the reduced space heat demand during the peak winter period does provide a useful comparison since the temperature match was quite good.

The elevation of the attic temperature at night due to the RBS can clearly be seen in Figure 30. The figure plots average heating demand and attic conditions for the five houses which had the radiant barrier installed and were heating on the comparison days. Note that the attic temperature is 2°F warmer at 6 AM in the post RBS retrofit period than it was in the pre period. The line crosses over at 10 AM, with the RBS attic colder between noon and 6 PM. This is not a problem, however, as little heating occurs in Florida during warmer mid-day hours.

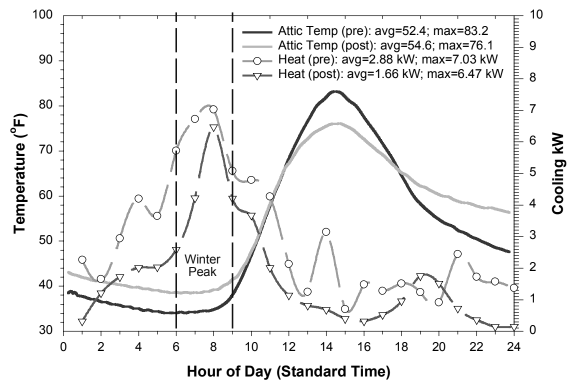


Figure 30. Heating load and attic temperature profiles for five RBS sites, pre (January 6, 1999) and post retrofit (January 5, 2001). Note warmer early morning temperatures with RBS during peak period. Attic temperature is only lower with RBS at mid-day.

Economics

An installed radiant barrier in new residential construction costs approximately \$0.15 - \$0.35/square of roof area. This cost was estimated through contacts with several vendors in Florida and Texas (Parker et al., 1991; Medina et al., 1994). Since Utility homes average 1,600 square feet and likely have roofs averaging about 2,000 square feet, this results in an incremental cost range of \$300 - \$750. The cost for retrofit in existing homes is highly variable, but may average \$0.50 - \$0.75 per square foot due to increased installation labor. The range of the costs is also in general agreement with the costs encountered in a residential retrofit program in Oklahoma (Ternes and Levins, 1992).

As seen from our data, average reductions to space cooling energy were about 9%. Individual savings should depend on pre-existing ceiling insulation, duct and air handler location and roof to floor area ratio. For a typical utility customer using 5,650 kWh per year for cooling, this would represent an average annual savings of about \$41. Since space heating energy savings are lower, the economics of RBS will be greatest for customers with high summer utility bills. Because of lower installation costs, economics will look best in new homes.

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)

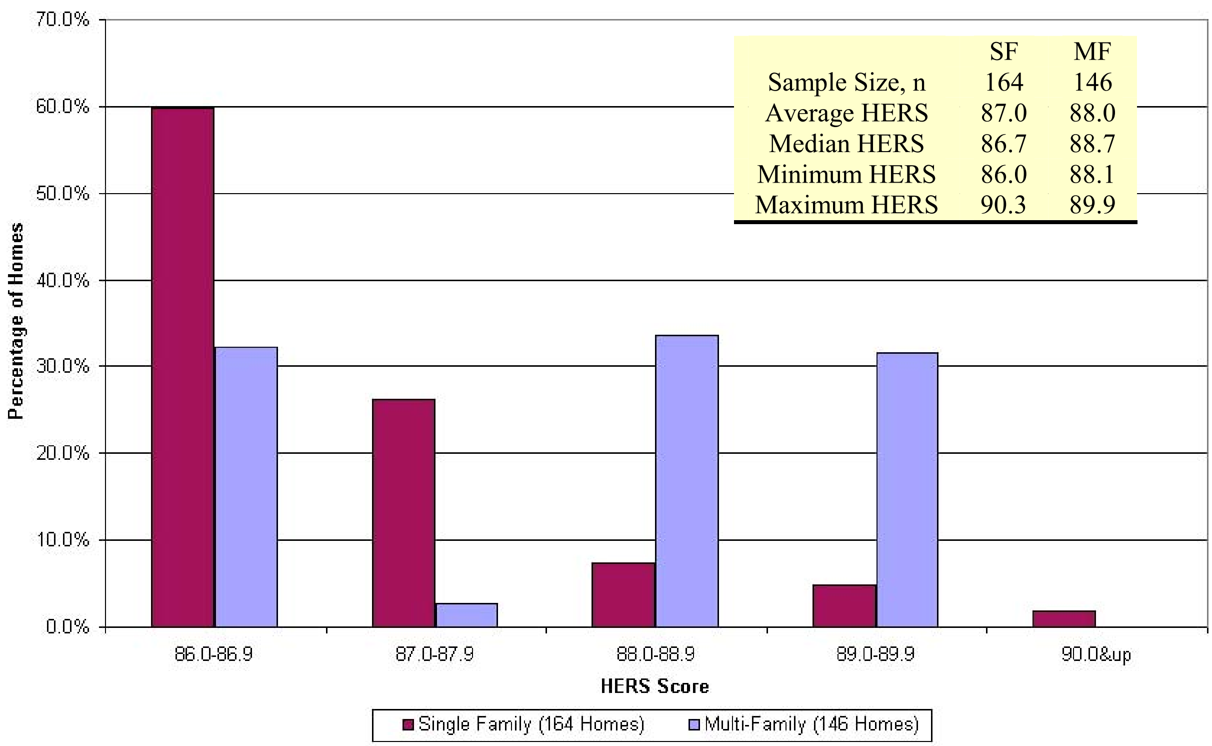

Figure 5 HERS Scores for FL H.E.R.O. Homes

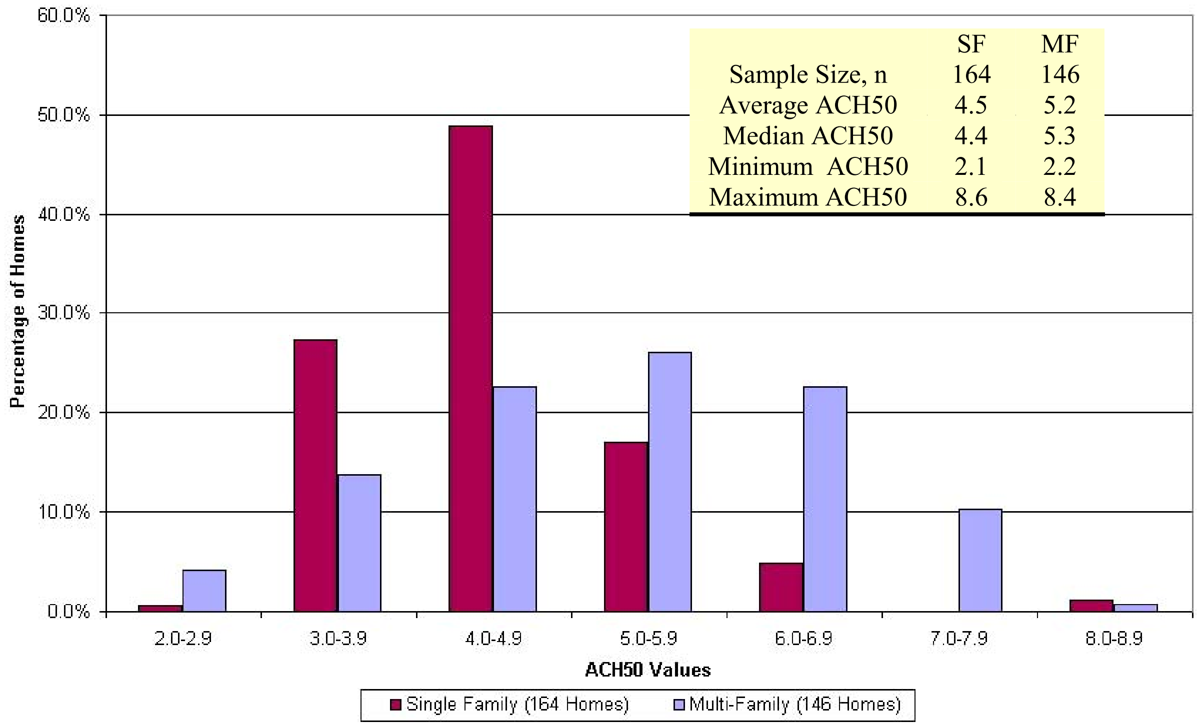

Figure 6 ACH50 Values for FL H.E.R.O. Homes

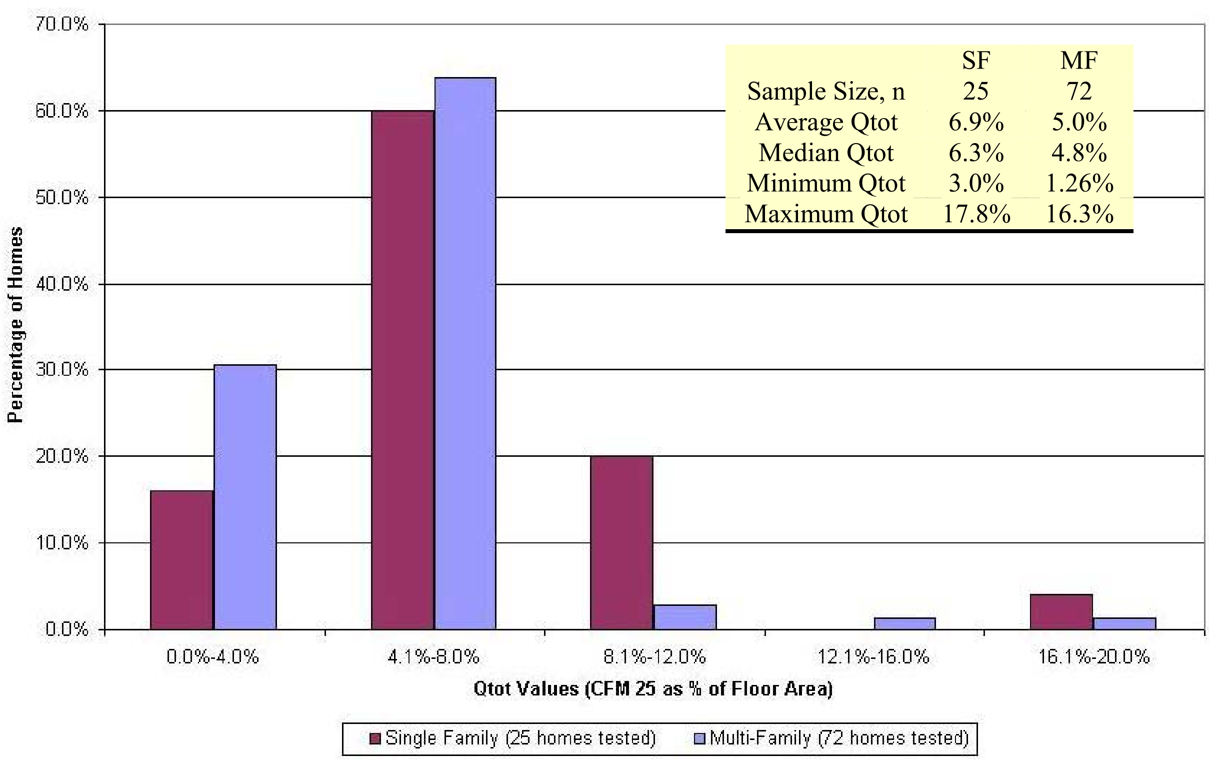

Figure 7 Qtot Values for FL H.E.R.O. Homes

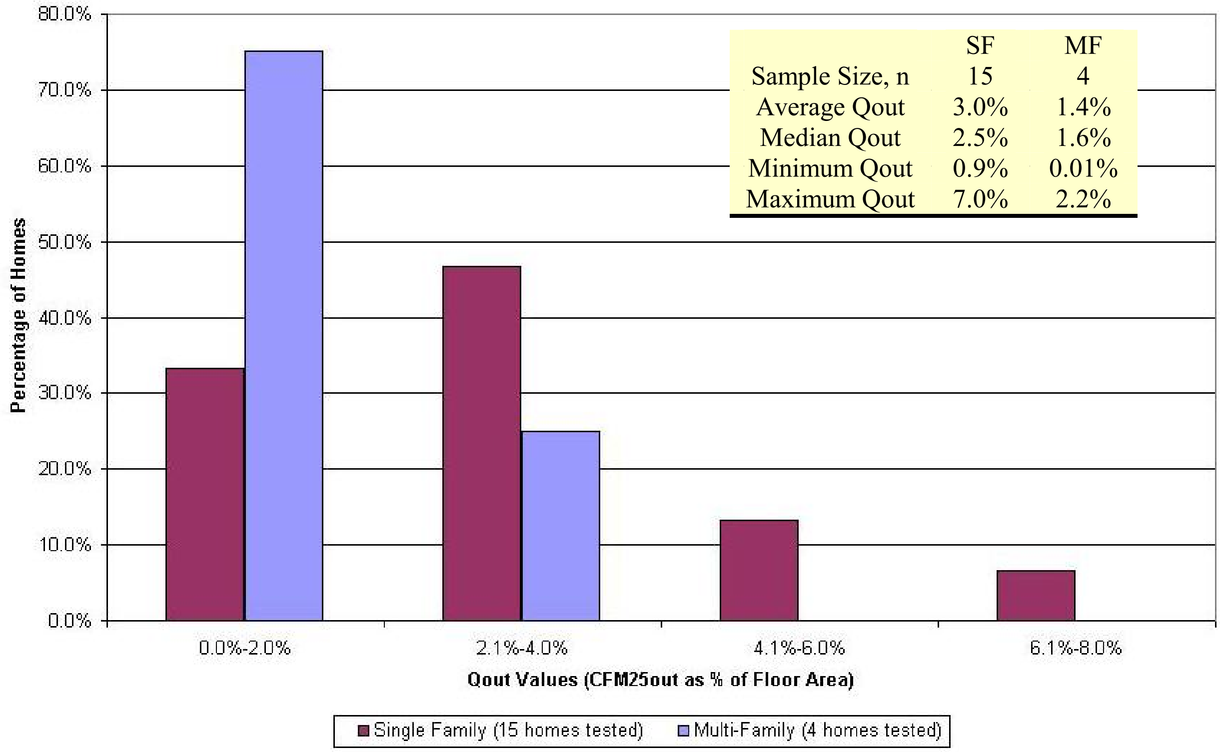

Figure 8 Qout Values for FL H.E.R.O. Homes

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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We are grateful to our sponsors, industry partners, collaborators and colleagues for this opportunity to make a difference.

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