Literature Review of the Impact and Need for Attic Ventilation in Florida Homes

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Literature Review of Attic Ventilation Impacts on Florida Homes for the Florida Department of Community Affairs

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Introduction

The Florida Department of Community Affairs (DCA) is seeking to examine the impact and necessity of residential attic ventilation in Florida homes. Here, we provide technical support by examining existing data sources on the impacts of attic ventilation both on cooling and heating energy use as well as to attic and home moisture levels. In particular we evaluate the issues with sealed attic construction where the attic is unvented and expanded foam insulation is applied directly to the underside of the roof decking.

We also report the data from Florida Solar Energy Center (FSEC) instrumented facilities to add unique information to the evaluation. This review emphasizes literature where there was extensive monitoring in Florida and other hot climates. Analysis of the empirical data suggest inferences on attic thermal performance and associated impacts on space cooling and space heating as well as attic moisture levels. Others potential influences are also discussed.

Natural Ventilation of Attics

Additional attic ventilation is a commonly advocated method to reduce ceiling summertime heat gains in residential buildings. Increased passive attic ventilation (wind and buoyancy driven ventilation) can be obtained by larger inlet and outlet areas or by adding a ridge vent to take advantage of the stack effect. Although various means of augmenting passive ventilation may be useful for new construction, this must be balanced from the emerging concerns of the impact of attic ventilation on attic and household moisture rates in very humid climates. Recent concerns associated with roof storm resistance against wind damage and water intrusion suggests the great importance of critical examination of roof/attic ventilation elements and their resistance to impact from storm events. Moreover, post mortem evaluation of roof systems after hurricanes show that where attic ventilation is used, effective ridge ventilation that retards rain intrusion is an important factor in reducing sheathing uplift damage and corresponding structural roof failure.[1] This is more thoroughly discussed with references later in the report.

Although the adequacy of attic ventilation rates to reduce moisture accumulation in colder climates has received considerable attention (Harrje et al., 1979; Cleary, 1984; Spies, 1987), the actual impact

[1] One manufacturer claiming such a product is *Air Vent* (Air Vent Inc. 3000 West Commerce Street, Dallas, TX 75212) . These products feature an external baffle which deflects wind up and over the vent, creating an area of negative pressure that causes lift and zone of negative pressure. This negative pressure works to pull air out of the attic. The baffle also deflects wind over the vent to help prevent wind-blown rain and snow from entering the attic.

on attic and whole house thermal performance is less well researched.[2] In one experiment where an attic was sealed, Wetherington (1979) found that attic ventilation made a moderate difference in attic air temperatures, but approximately a 5% impact on house indoor humidity. Unfortunately, the study measurements were made using crude equipment and the experiment appears to have been influenced by attic cooling system duct leakage. Harrje et al. (1979) found that experimental change from soffit vs. ridge ventilation seemed to make little difference on space cooling, but with the experimental periods too short, and with too varied weather conditions to reach valid conclusions. However, a carefully done simulation study of monitored Houston houses by Peavy (1979) estimated that ceiling heat flux would be reduced by up to 31% by effective ventilation vs. sealed operation. One investigation with particular relevance to the study was work done by the FSEC in its Passive Cooling Laboratory (PCL) in the summer of 1985 (Fairey, 1988). Here experiments examined how ceiling heat fluxes changed with vented or unvented attics in a series of tests. On average, natural ventilation of the attic space (as opposed to a sealed attic) was shown to decrease ceiling heat flux by 37% with R-19 insulation. Parker and Sherwin (1998) found that 1:150 ventilation with an attic radiant barrier would reduce heat flux by 36% vs. 26% against a radiant barrier with only 1:300 ventilation.

An important study by Beal and Chandra (1995) found that a sealed attic versus one ventilated to standard levels (1:300 with soffit and ridge venting) yielded a 32% reduction to attic heat flux. However, the same study showed that the presence of a ridge vent only improved ceiling heat flux reduction by about 4%. Unfortunately, the measurement duration during this study were very short (subject to weather) and there were some questions about the actual ventilation areas in the testing and how they compared to HUD levels (1:300 and 1:150).

Although attic ventilation has been shown to reduce attic air temperatures and cooling loads the only examination of powered attic ventilators has shown the electricity consumption of the ventilator fans to be greater than the savings in air conditioning energy (Burch et al., 1979). Research on the impact of natural ventilation rates on the thermal performance of attics and homes has received scant attention.

Code Requirements for Attic Ventilation

According to most building codes, residential homes need 1 square foot of ventilation or net free area for every 300 square feet of attic floor space (FHA, 2003). Net free area is the total unobstructed area through which air can enter or exhaust a non-powered ventilation system.

- For new home construction that includes a vapor barrier in the ceiling, the minimum is one square foot of ventilation or net free area for every 300 square feet of attic floor space.

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[2] Determination of typical *in situ* ventilation rates in residential attics is spotty. Grot and Siu (1979) took test data on three houses in Houston, Texas which had soffit vents. Measured ventilation rates using sulfur hexafluoride (SF_6) tracer gas tests for the attics were 1.7 to 2.3 air changes per hour during the month of August, 1976. Cleary and Sonderegger (1984) made several measurements using SF_6 tracer gas to measure attic air change rates at various wind speeds in a house in Oroville, California. They found rates of 0.023 m^3/s per m/s wind speed in an attic with 3,000 cm^2 of soffit vents. Given the volume of the residential attic, this equates to an approximate air change rate of 4.6 air changes per hour (ACH) at a 7 m/s wind speed. Using similar SF_6 equipment Ford (1979) measured attic air change rates of 3 - 4 ACH under moderate wind conditions in Princeton, New Jersey. Dietz et al., measured a rate of 2.9 ACH in a long term tracer gas test on an attic in an Illinois house (1982). In a number of experiments using SF_6 tracer gas in two attics in Ocala, Florida, Ober (1990)measured average air change rates of 0.9 to 1.8 ACH in two attics in test periods ranging from 2 to 27 days. The various studies agree that wind speed is the primary driver of attic ventilation with thermal buoyancy a significant secondary influence. Parker et. al. (1991) show a model of attic ventilation compared with measured data from FSEC's Passive Cooling Laboratory. This model showed that common daily attic ventilation rates vary from about 1 ACH at night to 4 ACH during windy afternoons.

- If vents are split between ridge vents and intake vents, the minimum requirement is also one square foot of ventilation or net free area for every 300 square feet of attic floor space.

- If no vapor retarder is used and/or proper distribution of under eave and ridge vents cannot be achieved (50% of ventilation as ridge vents), one square foot of net free vent area should be provided for each 150 square feet of attic floor or area to be vented.

- For a balanced system, ventilation should be equal at the under eave and ridge.

Codes vary somewhat in interpretation from one geographic region to the next. Some jurisdictions allow new sealed attic construction, while others do not. Although the 50% distribution rule within the code requires both soffit and ridge vents, it seems very unlikely that 1:150 is ever enforced based on calculation alone. Often, the code approval is based on the least common denominator: "building has perforated soffit vents and ridge vents = pass."

Adverse Impacts of Attic Ventilation

While there is consensus that attic ventilation can improve summer thermal performance, emerging evidence suggests problems with ventilated attics in humid climates. Recently, the issue of attic ventilation has become a contentious issue, in part due to the lack of scientific basis for the 1:300 free ventilation rate (Rose, 1995). Also measured and simulated influences of ventilation on humidity of attic materials suggest that attic ventilation may lead to problems in hot and humid climates (Burch et al., 1996; TenWolde and Rose, 1999). The major problem is that passively ventilated attics bring in large amounts of moisture laden air into the attics during evening and morning hours when relative humidity is often high.[3] This can lead to sweating air conditioning ducts (and air handlers) with associated insulation and even ceiling damage. A recent presentation of data taken in Gainesville, FL suggests that attic ventilation actually removes moisture from the attic space during day time hours (Porter, 2005). However, this test building did not contain cooling ducts that would allow evaluation of potential sweating problems during evening hours from attic ventilation.

Roof/Attic Ventilation Interaction with Potential for Hurricane Damage

Heavy rain in a hurricane adds to the danger of the storm as evaluated in detailed post mortem assessments conducted by HUD (1993) after Hurricanes Andrew and Iniki. Hurricane Andrew, a fairly dry storm because of its high forward speed, still dumped 10 inches of rain on south Florida and left many buildings extensively water damaged. Water seeping into gaps between the roof sheathing saturated insulation and ceiling drywall and caused some buildings to collapse (Wolfe et al., 1994). Rain quickly saturated the insulation and the ceiling. The loss of ceiling strength due to water saturation, and the increased weight of the wet insulation, caused widespread collapse of ceilings. Nearly 65% of homes exposed to Andrew, and 40% of homes exposed to Hurricane Iniki, had water damage.

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3 For instance monitoring of attic ventilation rates in a calibrated facility in 1987 (Parker et. al., 1991) showed nighttime attic ventilation rates averaging 0.5-1.5 air changes per hour. For instance, a typical 2,000 ft^2 home with a 5/12 pitch has an attic volume of 5,200 ft^3. With nighttime attic ventilation rates averaging one air change per hour this indictes this volume of moisture-laden outdoor air is introduced to the attic.

When houses were exposed to hurricane forces, roofs were most susceptible to damage, followed by walls and openings, and then foundations. The data show clearly that roofs are damaged more often than any other building component (Manning and Nichols, 1991). Roof coverings which were not adequately attached, and corner and eave and ridge regions of roofs were frequently damaged. Smith and McDonald (1991) note that in the Charleston area probably more than 75% of all roofs had at least minimal damage. Once roofs were breached, house interiors were exposed to further damage from water. Roof failures were also the most frequently observed structural failures from Andrew. Cook (1991) estimates that over 80% of losses were related to roof failures and associated water damage. In Dade County, Florida, the most common building failure observed was loss of roof cladding (shingles, tiles, etc.). Ninety percent of all homes in Dade County had some degree of roof damage (Doehring et al., 1994).

Water penetration was a major problem whenever roofing material was removed by wind action. For steep roof systems, many roofing failures occurred at the ridge or gable ends where wind_induced forces were the highest. Gable ends were consistently found to increase the chances of roof failure in a number of forensic tests after hurricanes. On the other hand, Cook et al. (1994) recommended that adding ridge ventilators could reduce uplift of roof sheathing from pressures exhibited from soffit-only ventilation. The same conclusion was reached in an evaluation of roof sheathing failures in the wake of Hurricane Andrew (Miller, 1993). Thus, ridge vents look important for hurricane resistance, but must effectively reduce wind-driven rain intrusion to prevent damage. Some newer models have external weather baffles along with internal weather filters. UL testing of these ridge vents supposedly evaluates their resistance to wind driven rain up to speeds of 110 mph, but we know of no independent other evaluation.

Forced Ventilation

Increasing attic ventilation rates in existing residential buildings is often accomplished by adding forced ventilation using attic temperature activated attic fans. However, even those who are in favor of increased attic ventilation have often warned that the energy consumption associated with the attic fan motor is likely greater than any realized energy savings from its use (Wolfert and Hinrichs, 1974). Also, an early detailed study showed that while forced attic ventilation did reduce cooling energy use, the reduction was quite small and outweighed by the energy consumption of the fan itself (Dutt and Harrje, 1979). Another study in two instrumented side-by-side homes in Texas came to similar conclusions (Burch and Treado, 1979). Forced ventilation was found to reduce ceiling heat gain by 1.1 Btu/hr/ft^2 (328 W) over soffit venting and gains to the attic duct system by 94 W.[4] At a normal air conditioning COP of 3, the overall reduction in cooling energy use could be expected to be approximately 140 W against the measured consumption of 284 W by the ventilation fan. Measured reduction to the maximum cooling load was only 6% for R-11 ceiling insulation. Thus, the powered ventilation does not typically result in a net energy savings unless the attic is uninsulated. Under typical construction scenarios, other means of controlling attic heat gain are preferable and more cost effective than forced ventilation. Other analysis, tends to verify this conclusion. Detailed simulations suggest that the heat transfer in an attic to a

[4] Interestingly, Burch and Treado (1979) found ridge or turbine ventilation to be nearly as effective as forced ventilation in reducing the overall attic temperature profile, producing an average reduction in the ceiling heat flux of about 19%. However, the authors concluded that this represented no more than a 3% reduction in the overall building cooling load under maximum conditions.

residential building interior in mid-summer is dominated by radiative gains from the hot roof decking directly to the insulation surface (Parker et al., 1991; Wilkes, 1991). This mode of heat transfer is more effectively limited by 1) increased attic insulation, 2) a truss-mounted radiant barrier or 3) a white reflective roof surface that limits solar gain to the attic structure.

Most attic ventilators often draw 250 - 300 Watts of electric power when in operation (they are typically triggered on when the attic air temperature reaches 105°F or more). For a single ventilator (often two or more are used), this level of electrical use (approximately 10% of the peak air conditioner power draw) is greater than the savings in space cooling energy (6% as shown by Burch et al., 1979).

Poor performance and unattractive economics serves as the main limitation to more common use of forced attic ventilation. There are other potential problems with powered attic ventilation. Tooley and Davis (1994) have found that powered attic ventilation can effectively cause negative pressures in combustion appliance zones – a potentially dangerous situation – as well as drawing conditioned air from the building interior through leakage in the ceiling/attic interface. This could serve to increase building cooling latent loads and offset any potential energy savings associated with powered attic ventilation.

Another solution is to use ventilator fans with no parasitic electricity consumption beyond what is generated by the unit. Typically, this involve using photovoltaics to power ventilation fans. Such solar powered attic ventilators are now commonly available. One intrinsic advantage of a photovoltaic powered attic ventilation scheme is that the attic is well ventilated only during daytime hours only when considerable insolation is present. Coincidently, these also tend to be periods when the ambient relative humidity is low. This method will not effectively ventilate the attic during humid nighttime periods nor during rainy periods when outdoor moisture is high. Also, so attic ventilation can be switched off in the event of adverse weather by providing switching for the ventilators. One other advantage of the PV ventilators over AC powered units is noise. Although not quantified within a previous study, we did note that PV vent fans are very quiet in operation compared with the very noticeable fan noise generated by conventional units.

A case study was performed on two photovoltaic attic ventilator fans retrofitted into an occupied 1500 square foot family home in Central Florida (Parker & Sherwin, 2000). Comparing periods with similar weather conditions, the test revealed that the PV vent fans have the potential to reduce measured peak summer attic air temperatures by over 20°F. However, the impact over the cooling season is fairly modest with well insulated attics. Measured space cooling reduction was approximately 6% – worth about 460 kWh annually at the test home. Still, this strategy may have other benefits relative to attic humidity control and the ability to halt ventilation by simple switching during extreme weather events. Although PV ventilators claim to be resistant to wind-borne rain intrusion, independent testing would be desirable.

Measurement of Attic Ventilation Impact in Hot Climates

Rose, 1992

Rose (1992) compared attic temperatures in a test facility of several bays with different attic construction. Comparisons of vented and unvented flat-ceiling attics showed that the maximum attic air temperature was 28°F cooler with vents than without. This is not an average number, so it is likely that seasonally the difference is much smaller.

Beal and Chandra, 1995

Beal and Chandra (1995) compared different ventilation strategies in a test facility in Florida to evaluate the effect on the temperature difference across a ceiling insulated to R-19. The reference case used a low profile ridge vent with a perforated soffit vent, which had a peak temperature difference between 30°F and 40°F during the different tests.

Using a high profile ridge vent with an open soffit reduced the temperature difference by 25%. Keeping the perforated soffit vent, but using either a high profile ridge vent or no ridge vent had less than a 5% impact on the temperature difference. Closing all vents increased the temperature difference by 32%.

Parker and Sherwin, 1998a

Parker and Sherwin (1998a) performed tests on 6 adjacent roofs in a Florida research facility to evaluate the effects of methods to reduce the heat flux across an R-19 ceiling. Among those options considered were a radiant barrier system and increased ventilation. This study was partly prompted by a previous study in Florida that showed that, in 48 homes, those homes with the cooling system air handler in the attic used 30% more cooling than those with the air handler elsewhere (Cummings et al. 1991).

Testing was done in the summer of 1997. With 1:300 vent area, adding the radiant barrier system reduced the ceiling flux by 26%. Increasing the vent area to 1:150 improved the reduction to 36% (an additional 10 percentage point reduction) while increasing the relative humidity in the attic by 6-10%. The average humidity without the radiant barrier system and with 1:300 was 53%, when the radiant barrier system was added the average was 54%, and when the vent area was increased to 1:150 the average relative humidity increased to 62%.

Parker and Sherwin, 1998b

Parker and Sherwin (1998b) did another study in single-family residences in Florida. Homes were monitored from June through September, 1996. The 21 homes had varying roof colors and ventilation strategies. Of the 21 homes, ten had shingles and both soffit and ridge venting. Four had shingles and only soffit venting. The remainder of the homes were evaluated for characteristics other than venting.

Examining when ambient temperature was at the 2.5% design temperature, the 10 attics with both soffit and ridge vents averaged 22°F higher than ambient. The 4 homes with only soffit vents averaged 35°F greater than ambient under the same conditions.

Sealed Attic Construction

Sealed attics (sometimes referred to as "unvented cathedralized attics") have their insulation and air pressure boundary at the plane of the roof (and gable ends) instead of at the ceiling plane (Rose, 1995). The typical attic volume is intentionally sealed to the outdoors. Since the home's insulation envelope is at the roof instead of at the ceiling, what would normally be an attic is now really part of the home's conditioned space. This is because normal ceiling drywall provides low resistance to heat conduction (R-0.45 hr ft^2/Btu-°F). The attic is now actually inside the home with the space unintentionally conditioned. However, it may be be3neficial to provide thermal and air coupling through the ceiling which is nearly inevitable with the numerous recessed cna lights in modern homes. An unvented-sealed attic differs from a cathedral ceiling, whether vented or unvented, in that the cathedral ceiling has interior finish materials installed beneath the roof framing and insulation, whereas, the insulation and framing are left exposed within the attic space with an unvented and sealed attic. A schematic comparison of sealed attic versus ventilated attic construction is shown in Figure 1.

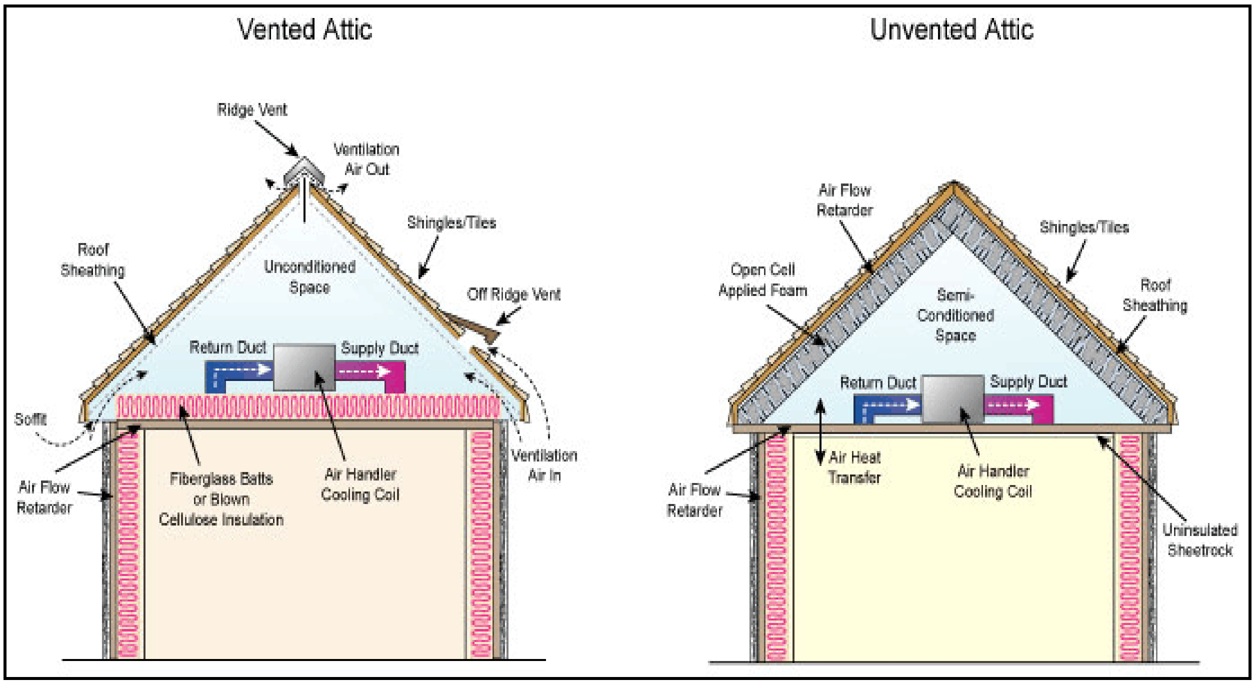

Figure 1. Diagram of Roof/attic thermal processes in vented and sealed attics.

Typically the roof decking is insulated in a sealed attic by application of expanding spray foam insulation directly applied to the underside of the roof sheathing and gable end walls. This has been useful in hot-humid climates to remedy moisture related problems due to condensation of moist outdoor air on cool supply air ducts, air handlers or sheet rock surfaces (Lstiburek, 1993). While the extra expense of correcting a moisture problem can be justified, it is often harder to sell a premium option for the price sensitive new construction market. Thus, less expensive methods of cathedralizing have been advocated, such as netted-and-blown cellulose, and strapped-in-place fiberglass batts. The spray foam application inherently eliminates air movement, whereas the fibrous insulation application allows air movement which can cause moisture condensation on roof sheathing depending on the sheathing temperature. The foam insulation is also a good air barrier and helps to better seal the attic.[5] Recently, field data has become available form the Conservation Service Group which evaluated correlation between airtightness and insulation type in a large sample of homes in Massachusetts and Rhode Island. All homes were blower door tested after construction (EDU, 2005). Within that study, 466 homes with fiberglass insulated ceilings had an estimated natural air change rate of 0.40 air changes per hour (ACH) against 0.24 ACH for 18 homes in which the ceiling/roof was insulated with spray polyurethane foam similar to that use with the sealed attic.

Also, there are concerns with bagged (suspended) loose fill insulation under decking. The concerns revolve around two issues. Firstly, low density insulation thermal conductivity may be compromised by temperature conditions present in attics. The temperature dependence of thermal insulation conductivity is widely acknowledged (ASHRAE, 2001, Turner and Malloy, 1981). Changing conductivity with mean temperature of insulation is not an inconsequential factor with loose fill insulation. Since loose fill insulation is rated at a mean temperature across the insulation of 75°F, increasing this to 100°F as would be seen in an insulated roof deck would typically see rated system R-values reduced by 15% or more (Tye et al., 1980). Also coverage of trusses (and inevitable gaps) will often lead to increased heat transfer relative to foamed installation where the trusses are well covered. Netted, blown or strapped in place fiberglass batts are not recommended for this application in hot humid climates, even by former advocates (Rudd, 2005) because of moisture migration within the insulation toward roof peaks where condensation can occur in cold weather.

In some cases sealed attics can have energy performance advantages over ventilated attics. Air conditioning ducts are most often located in the attic of slab-on-grade homes (most Florida homes). If the insulation for the under the roof decking of your home is located in the roof instead of in the ceiling, then these ducts remain in a cooler space which can result in air conditioning energy savings. Duct leakage is also problematic in many homes, often with much of the air leaking into the return side of the air handler system coming from the attic. A sealed attic will reduce the energy waste associated with these duct leaks. Additionally, with water-front properties, sealed attic systems can have additional advantages related to keeping wind-blown moisture and salt-laden air out of attics.

Side-by-side roof research tests, one with dark gray shingles (solar absorptance of 92%) over a vented attic compared with dark gray shingles over a sealed attic, have shown 9% cooling energy savings for the sealed attic with typical attic duct construction. Tests of vented attics comparing the dark gray shingles with white shingles (solar absorptance of 76%) found savings of 4% for the white shingles. This indicates that combining white shingles with a sealed attic is likely to produce greater cooling energy savings. In addition, these tests found significantly greater savings (17-23%) for white tile and white metal roofing systems. Measured energy performance savings of 9% have also been reported in separate field tests for attic radiant barrier systems in monitored homes (Parker, et. al., 2001).

Measurements also have shown that sealed attics and attics with radiant barriers have hotter roofs. This occurs because heat can not readily leave the inward side of the roof sheathing if it is insulated.

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[5] Eliminating attic ventilation also likely improves overall house airtightness. All things equal, such greater airtightness could be expected to reduce energy use and moisture control. Within the FPL study (Parker, et. al., 2001), the sealed attic house had a leakage rate of 4.5 ACH at a 50 Pa pressure, whereas the control house had a leakage rate of 6.9 ACH50. The other five similar houses in the study had leakage rates of 5.5-6.0 ACH50.

By way of comparison, for the sealed attic roof with dark gray shingles, the measured top-surface peak shingle temperatures are about 7°F hotter than the otherwise identical vented attic. The temperatures at the bottom of the roof, between the roof decking and the roof insulation, however, are about 23°F higher at peak than in the vented attic. For attic radiant barrier systems, measured peak shingle temperatures are about 5°F higher and peak temperatures at the bottom of the roof sheathing are about 12°F higher.

Other tests comparing white and black shingles have shown that shingle color makes a greater difference in peak shingle temperature than the presence or absence of attic ventilation or an attic radiant barrier system. These tests, accomplished at the FSEC Flexible Roof Facility (FRF), showed peak temperatures for black shingles (solar absorptance of 97%) to be almost 25°F hotter than peak temperatures for white shingles (solar absorptance of 76%). Thus, if elevated temperatures can result in composition shingle failure, then the problems are likely to be much more pronounced for darker shingle products, especially in climates with large quantities of solar radiation.

In general, cooling energy savings will be greatest when sealed attic and insulated roof deck construction is used in combination with more reflective white tile or metal roofing materials. However, if an insulated roof deck and sealed attic are used with composition shingles, the following options will improve savings and potentially lower system temperatures seen with this construction method:

1) Selection of white-colored shingles will tend to be much cooler under full sun. White colored shingles also produce the greatest cooling energy savings among shingle roofs.

2) Using thicker roof sheathing and high-quality, heavy-grade shingles, preferably from a company that will warranty their product in a sealed attic with an insulated roof deck.

3) Consider using a roof assembly with a ventilated air space above the insulated decking (a double roof). This creates a vented decking surface on which the shingles are installed. This is the installation recommended by the Asphalt Roofing Manufacturer's Association (ARMA) to reduce shingle temperatures for sealed attics (see also the links given below).
   Proper ventilation for shingle roofs: http://www.asphaltroofing.org/pdf/tb_209.pdf
   Shingles over insulated roof decks: http://www.asphaltroofing.org/pdf/tb_211.pdf
   These two publications are provided at the end of the report as Appendix A and B, respectively. Also, test results for his configuration are shown later in this report.

Most composition shingle manufacturers claim that their warranty will be voided if the bottom surface of the roof sheathing is not vented. One published reason indicates that attic ventilation keeps shingles from reaching excessively high temperatures and reduces the rate at which oxidation and hydrocarbon volatiles are driven off that make aged shingles become brittle (Terenzio, 1997). The role of temperature versus UV exposure is not well known, although temperature is commonly cited as having a critical role in shingle longevity (Cash and Lyon, 2002). However, experiments shows that ventilation is a lesser factor in resulting shingle temperature than is shingle color or geographic location. Rose (2001) showed that ventilation of a black shingle covered, truss framed roof only reduced temperatures by 2-3% whereas the impact of color was 20 - 30%. FSEC testing at its Flexible Roof Facility (Parker and Sherwin, 1998a) also shows that roof color and reflectivity is a very large effect– and larger than ventilation. Cash and Lyon (2002) showed through computer simulation that shingle temperature is a larger function of geographic location or roof facing direction than it is attic ventilation. However, as is shown below in data taken by FSEC and BSC, suspension of attic ventilation will increase peak temperatures of shingles by approximately 7°F and average temperatures will increase as well.

On the other hand, two shingle manufacturers, *Elk Shingles* and *Certainteed*, warranty their composition shingle products for sealed roof applications with foam insulated roof decks. *Certainteed Corporation* specifically warranties its shingles that meet ASTM D3462 when used with an insulated roof deck with 3/8" plywood decking of 7/16" OSB.[6] *Elk Shingles* has product specifications by manufacturer's insulation product. Note also that these slightly elevated roof temperatures are unlikely to affect tile, metal or single-ply membrane products. Thus, if a sealed attic system is used with composition shingles, it is good policy to make sure to use a product that does not warn against unvented sealed attic or insulated roof deck applications.

On the other hand, research summarized by Roodvoets (2001) suggests that any focus on average shingle surface temperature misses the key function of time and temperature in impacting the aging process for composition shingles. While average shingle temperatures may only be increased by a degree or two, the time at higher temperatures can be considerably increased by lower ventilation levels. Also, the shingle temperatures cannot be expected be uniform. With convective cooling at the surface, the shingle surface may show much less difference than the underside of the shingle which is better characterized by the decking temperature. As shown by Parker (1998 and 2000), decking temperatures show much larger increases to temperature with reduced ventilation (the data from Parker (2000) showed an average increase in the decking temperature of 3.7°F during summer). Thus, the average increase in shingle temperature may be much higher than the upper surface measured value. As demonstrated in the 1888 by Svante August Arrhenius, fundamental chemical molecular activity essentially doubles for every 18°F of increase in temperature. As shingle degradation is large a function of oxidation, the rates of this decomposition can be expected to follow the laws of chemical reactions. Accordingly, if the average shingle temperature was elevated by 2°F, the shingle life expectancy might be reduced by 11%.

Perhaps the most rigorous analysis of the impact of attic ventilation on shingle life comes from work sponsored by the *Certainteed Corporation* (Shiao et al, 2003) in which the authors developed a mathematical model of cumulative shingle damage to evaluate the kinetics of roofing material degradation. Again, this work showed that fundamental increases to molecular activity were the fundamental driving force in reducing shingle life expectancy. In particularly, the high temperature history in a hot climate was showed accelerated aging of composition shingles. For instance, the higher temperatures in a hot climate such as Miami, were shown to accelerate aging during during winter months at a rate about 10 times faster than in Minneapolis. The effect of attic ventilation was found to reduce the uneven distribution of cumulative damage across the roof deck due to unbalanced thermal regimes in the unvented roof deck as well as to reduce the times at higher temperatures. The work did not look at how no ventilation and an insulated roof deck would influence the time-temperature history, but there is little doubt that such an evaluation would find even larger differences in the rate of cumulative shingle aging (Shiao, 2005).

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[6] Personal communication with Jody Caldwell, *Elk Corporation*, 14911 Quorum Dr., Dallas, TX 75254, 972/851-0400. See Certainteed, 2005 Asphalt Shingle Products Limited Warranty, *Certainteed Corp*., Roofing Products Group, P.O. Box 860 Valley Forge, PA 19482, (800-345-1145).

There is one potential conflict with foam insulated roof deck within the current Florida residential building code. To provide fire resistance, Section R314 within the code (Florida Building Code, Residential, 2004) specifically requires that foam plastic insulation within the attic is protected against flame ignition by 1 1/2" thick mineral fiber insulation, or wood or hardboard panels or 3/8" gypsum board on the side that is exposed below. It is noteworthy, however, that foam insulations applied to roof decking are almost never installed in this manner. However, this space below the insulated roof deck is not really a habitable space and thus, it is up for interpretation as to whether the sheet rock ceiling below can serve as the required fire barrier. To allow for insulated roof decks done in this fashion, the provisions of the Florida code would have to be modified or the requirements clarified for approved sealed attic construction.

However, in another potential influence, sealed attic construction may also reduce the incidence of house fires during wildfire events, similar to those experienced in Florida in 1998. Research at the University of California by Stephen Quarles (2002) shows that soffit vents are vulnerable to flame and ember entry, and were associated with many structure losses in the 2003 wildfire in southern California. Quarles estimates that elimination of soffit and ridge venting in homes would those reduce fire spread rates in residential neighborhoods during wildfire events.

Literature Review on Sealed Attic Technology

Rose, 1995

Rose presented results from two years of detailed monitoring of cathedralized attics sections (not sealed attic construction) in the cold climate of Illinois. The study was done to evaluate whether there was potential for moisture damage of sheathing in cathedralized attic sections which are increasingly popular. This was an extension of preceding work on sheathing moisture levels (Rose, 1992). The work concluded that having a slot for an air chute above the insulation, but below the shingle covered roof decking was important to avoiding problems with excessive moisture content in the sheathing. Peak wood sheathing temperatures during summer were also reduced by about 4°F for south facing sections (173° vs. 177°F).

Rudd et al., 1996

A study in 1996 using both monitored and simulated analysis of homes in Las Vegas showed that the sealed attic concept was very viable in a very hot climate when used with tiled roofs. The homes with tiled sealed attics showed tile temperatures no greater than 3°F greater than with the vented attics. Sheathing temperatures were increased by a maximum of 17°F to 126°F for the sealed attics which was found to be less than the temperature variation experienced from changing from tile to asphalt shingle of any color. It was also well within the range of the maximum recommended temperature for sheathing (180°F). The study also found that with foam insulation on the roof decks that the homes and duct systems were considerably more air tight with respect to outdoors relative to the homes with vented attics, but with the same roofing tiles. Cooling energy savings were also demonstrated. This study underscores that the application of sealed attics to homes with tiled roofs generally appears acceptable without any major change to roofing system technology.

TenWolde and Rose, 1999
This study evaluated the various issues associated with sealed unvented attic constructions, based on a survey of available data. The study concluded that:

- Attic ventilation is recommended in cold climates to prevent sheathing moisture increases and potential for ice dam formation
- Ventilation is recommended only as a design option in hot and humid climates
- Although attic ventilation does slightly reduce summer shingle temperatures, the impacts of shingle color and geographic location are much larger.
- Issues that impact shingle durability are poorly understood.

Rudd, Lstiburek and Ueno, 2000
This paper extended on previous work done in Las Vegas with longer term monitoring and analysis of side-by-side data on vented and unvented attics. Additional test houses were also constructed, both in Las Vegas and Tucson, Arizona. The analysis showed approximately a 5% cooling energy reduction associated with sealed attics. Heating related savings looked to be even larger. Monitoring of a smaller installed AC system also revealed this as a viable strategy compared with the indicated sizes by *Manual J 7th Edition*. It is worthy to note, however, that the newer *Manual J 8th Edition* would give the sealed attic technique credit that would allow for a smaller installed air conditioning system.

Rose and TenWolde, 2002
In a detailed survey article for the ASHRAE Journal, Rose and TenWolde present a comprehensive literature review assessment of the codes related to attic ventilation and the scientific justification for those recommendations. Their review shows that the primary justification was for moisture control in cold inland climates where the considerations are very different than in milder and hot and humid climates. The primary reason for the 1:300 ventilation rate was to reduce moisture accumulation on sheathing during cold weather and to prevent ice dams. No scientific claims have been made that attic ventilation is needed for moisture control in hot humid climates where the authors show that attic venting tends to increase rather than reduce moisture levels in the attic. As air conditioning ducts (and sometimes air handlers) are often located in the attic space in slab on grade homes, introduction of moist outside air can result in condensation on ducts and potential moisture damage. The impact of attic ventilation on energy savings was not estimated in the study, but previous studies are cited in which the impact was small (<5% on space cooling).

Hendron et al., 2003
Field test of vented and sealed attics in Las Vegas Nevada and Tucson Arizona was shown to produce negligible energy savings when the duct system was tight. However cooling energy savings were clearly seen when the duct system was leaky. Under typical circumstances with 10% duct leakage, sealed attic construction was shown to reduce cooling energy use by about 8%.

Rudd, 2004
In 2004, Building Science Corporation (BSC) conducted a comprehensive review of sealed attic technology (which they refer to as unvented-cathedralized conditioned attics) for the U.S. Department of Energy (Rudd, 2004). This review not only described the technology and fundamental issues, but more importantly, it provided data and experience from numerous projects using sealed attic around the United States. A number of the measurement studies were done in hot-arid and hot-humid climates with relevance to conditions within our state. Monitoring efforts in hot

portions of Arizona and California found that an attic thermal distribution system is very close to being within the conditioned space relative to temperature, pressure and air leakage measurements.

California Homes

Testing of 10 homes in Banning, California showed that the temperature conditions within sealed attics were essentially at the same conditions as the actively conditioned space. This did not change with variation in the leakage and pressure differential test results. Hence, the current thinking is that the sealed attic space behaves similarly to the actively conditioned space below it when it meets a relatively tight building enclosure leakage criteria with the attic access open. Within the study the pressure difference was measured across the ceiling between the attic and living space with the attic access hatch closed and the living space depressurized to -50 Pa relative to outdoors. If the attic is perfectly sealed to outdoors and the ceiling is leaky, the pressure difference across the ceiling would be near zero.

If the attic is leaky to the outdoors, the pressure difference across the ceiling would trend towards 50 Pa. The attic access open depressurization test is used to insure that the building enclosure meets an established criteria of less than 0.25 cfm/ft^2 of building surface area. Measured results for the ten houses showed that the roof plane was about 70% of the total roof air pressure boundary while the ceiling represented only about 30%. This means that with the sealed attic method properly employed that the roof is the primary pressure boundary and that there is good communication between the attic and conditioned space through the ceiling. However, the results from this project and others suggest that inspections should be done with homes with sealed attic to insure that they are truly sealed. This would include verification that attic ventilation products are not used and that openings to the outdoors are eliminated. This is particularly important as this as sealing along soffits, gables and the roof itself is contrary to current building construction practices.

Testing of indoor thermostat temperatures compared with those taken in the sealed attic showed that during the cooling season the attic was between -2 and +5°F of the conditioned space. The average temperatures across the cooling season showed an average of 75°F within the conditioned space against an average of 78°F in the attics.

Phoenix, Arizona Homes

BSC monitored four homes with sealed attics near Phoenix, AZ. Within the homes, the roof sheathing temperature reached a peak of 150°F, while at the same time, the house was conditioned to a steady 78°F and the sealed attic was at most 10°F warmer than the actively conditioned space. Typically, the sealed attic was only 4°F warmer than the actively conditioned space for most hours.

Houston, Texas Homes

The report correctly points out that locating ducts inside conditioned space via sealed attic construction should have the most benefit in hot-humid climates due to the exclusion of exterior moisture from the space where the air distribution system is located. Air distribution system losses are much greater if return-side duct leakage unintentionally draws in exterior moisture (latent heat). More than twice as much energy is required to reduce the air dew point by 20°F as to reduce the air temperature by 20°F.

Monitoring of sealed attic homes in Houston with netted and blown insulation under the roof sheathing (rather than more expensive expanding foams) showed two problems:

- It became more difficult to achieve an air tight attic with respect to outdoors since the loose fill and blown insulation did not achieve the same level of leakage control.

- It became apparent that solar driven moisture through compositions shingles was driving moisture to the interior of the attic space.

Then later phenomenon occurs during summertime and the swing seasons in hot-humid climates when nighttime roof temperatures are depressed below the outdoor dew point temperature due to night sky radiation, causing moisture to condense on the roof surface. Thus, in the morning, the roofs are generally wet. Likely via capillary action, some of this moisture is drawn into the material of the composition shingle, and between the laps of shingles. Solar radiation subsequently heats the roof surface, elevating the water vapor pressure, which drives water vapor into and through the roof assembly.

To avoid this problem two prescriptive methods were employed.

C Netted or blow cellulose insulations systems are avoided in hot and humid climates to provide both a better attic seal to the exterior as well as to decrease vapor transport to the underside decking. This is done through the use of a low air permeance expanding foam.

C The solar driven moisture load is eliminated by installing a vapor retarder roof underlayment of one perm (water vapor transmission ASTM E96) or less beneath the composition shingles). This is also in accordance with the provisions of the IECC code within section R806.4 for “Conditioned Attic Assemblies.” Such roof underlayments are used instead of traditional 15 lb felt roofing paper, which has a water vapor transmission of about 6 perm, and are commercially available as *Flexia Tri-Flex*-30, *Titanium UDL*, and *Typar RoofWrap 30* with water vapor transmission of about 0.54 perm. The material costs about $0.08/ft^2 or about 3 to 4 times that of 15 lb felt.

Within the monitoring, some of the sealed attic homes recorded plywood sheathing temperatures that exceeded 170°F for short periods. While this is considered generally acceptable (TenWolde and Rose, 1998), there has been some concern over temperature related degradation experienced with fire retardant treated plywood (Winady and Beaumont, 1995). However the same studies showed that roof solar absorptance was a much larger factor on sheathing temperatures than attic ventilation. Within the evaluation, he simple expedient of light colored shingles vs. dark colored shingle could reduce peak sheathing temperatures by 10-20°F.

<u>Jacksonville, Florida</u>

A side-by-side study of sealed attic construction vs. a vented attic was conducted in Jacksonville, FL in 2001. Temperatures were measured of the composition shingles in both homes. The maximum temperature of dark gray-black south facing shingles was 180°F under the insulated roof deck with the shingle temperatures being 7°F cooler with the ventilated attic. Over the entire month of monitoring the sealed attic shingles averaged 0.2°F warmer than those over the standard vented attic. Cash and Lyon (2002) reported a calculated annual average temperature increase of 0.9°F for sealed vs. vented attics. This study also provided estimates showing that annual average attic temperature increases were associated with reduced expectancy of shingle roof longevity. Based on this work, the authors estimate that a 1 Centigrade increase in the mean annual temperature of shingles is equal to about three month reduction in the service life of the roof. However, the authors found that in Miami the average increase in annual temperature of the shingle roof was about 0.5°C (0.9°F) for vented vs. unvented construction whereas changing to white shingles would reduce the annual temperature by 1.5°C (2.7°F) or three times the variation induced by attic ventilation. Moreover, the authors also found that geographic variation outweighed other considerations: the average annual temperatures of shingles in Miami and Green Bay, Wisconsin varied by 18 Celsius (32.4°F).

In winter, if the roof sheathing temperature goes below the sealed attic air dew point temperature for long periods, condensation can occur on the bottom of the sheathing. This was observed near roof peaks in both Houston, TX and Jacksonville, FL with cellulose and fiberglass insulation, but not with low-density foamed deck applications. The low density expanding foam is permeable to water vapor (10 perm at 5 inch thickness), but unlike fiberglass and cellulose insulation, it is air impermeable (ASTM 2004). Because air does not move within or through the product, moisture is not carried to the cold roof sheathing. This again argues that if sealed attic construction is utilized in Florida that it only allow low air permeability expanding foams to be used for the application.

Finally, Rudd's evaluation pointed out some other potential advantages of sealed attic construction: reduced opportunity for insect and rodent infestation in attics. Research by Richard Brenner (1991) shows that lowering humidity in attics makes the spaces less hospitable for cockroach infestations. While the research suggests that one method to reduce attic relative humidity is through more effective ventilation, the research did not specifically evaluate impacts on humidity produced by sealed attic construction with deck insulation. More recent evaluation by Lstiburek (2005) showed that potential for soffit rainwater intrusion with high wind speed storms would be reduced.

FSEC Research on Sealed Attic Construction

Florida Solar Energy Center has extensive experience with attic monitoring attics in laboratory and field experiments as well as much work on attic thermal performance simulation models. FSEC performed comparative experiments on sealed attic construction for the U.S. Department of Energy that has shown the promise and pitfalls of this new attic construction method. Empirical data from these experiments will be made available with in the review as well as test cell data from the Flexible Roof Facility (Parker et. al, 2000).

Testing at the Flexible Roof Facility at Florida Solar Energy Center

Since 1988 the Florida Solar Energy Center has operated an attic/roof research facility called the Flexible Roof Facility (FRF) at its auxiliary research site in Cocoa, Florida (Figure 2). This facility was specifically designed to conduct side-by-side, in-situ attic/roof system performance tests for a wide variety of attic and roof configurations. The FRF comprises six 6-foot wide by 24-foot long attic/roof test sections mounted over a single, well mixed 40' by 24' conditioned space. Each attic/roof test section is well segregated from its adjacent test sections (or attic buffer spaces) by four 3/4" sheets of foil-faced isocyanurate insulation separated by air spaces.

Figure 2. FSEC Flexible Roof Facility showing roof/attic test cells under test. The 2 test cells with the dark composition shingle roofs are the subject of this report.

Data reported here result from a series of tests conducted during summer 2000. One of these tests was conducted specifically to compare the performance of insulated roof deck, sealed attics with conventional attics. For these tests, both attic systems consist of conventional roof trusses with 1/2" plywood sheathing covered by 15 lb. roofing felt and dark (absorptance = 0.97) composition shingles. The "conventional" attic/roof system contains R-19 fibrous batt-type insulation at the ceiling plane. This attic is vented by outdoor air using soffit and ridge vents and is hereinafter referred to as the "vented" attic. The other attic/roof system contains 6 inches of spray-applied, open-cell foam insulation system at the roof plane (R-value ~ 22 hÅft2ÅoF/Btu) that serves to both insulate the attic space from the outdoor environment and seal it from outdoor ventilation airflow.[7] There is no ceiling insulation in this test space, which is hereinafter referred to as the "sealed" attic.

<u>Results for Sealed Attic Construction</u>

Attic Air Temperatures

The average summer day mid-attic air temperature profiles for the sealed attic case and the ventilated attic are shown in Figure 3. The profiles show the impact of the sealed attic system in reducing summer cooling energy use associated with attic duct heat gains and loads from unintended air leakage coming from the attic zone.

[7] The properties of the open cell foam used for these tests are as follows: R-value = 3.6 hÅft2ÅoF/Btu per inch as measured in accordance with ASTM Standard C-518; water vapor permeability = 10-16 perms as measured in accordance with ASTM Standard E-96; air permeability = 0.0049-0.0080 l/sÅm2 @75 Pa in accordance with ASTM Standard E-283.

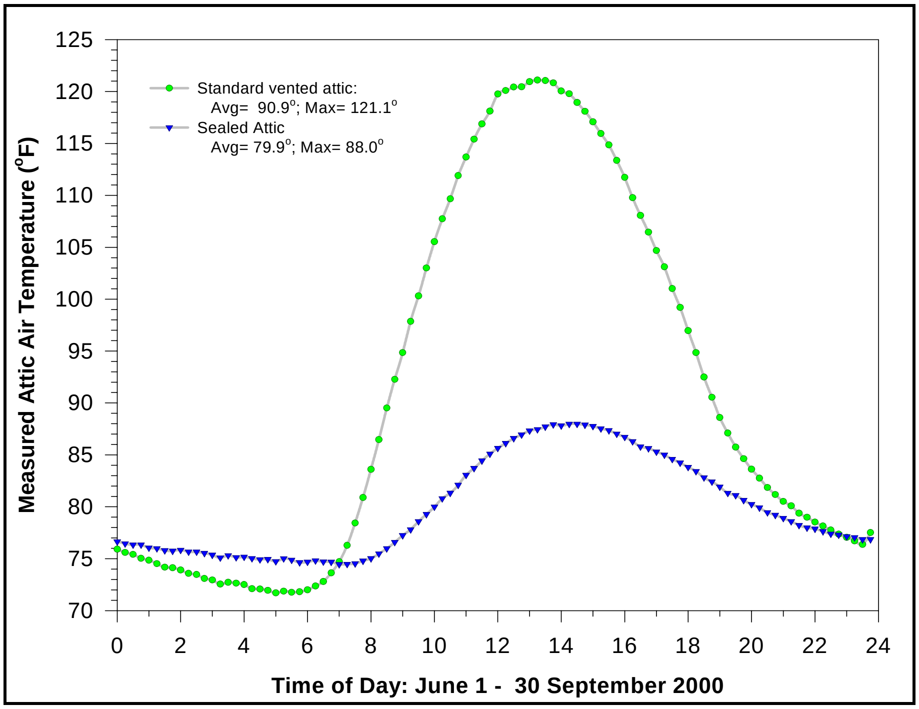

Figure 3. Measured average mid-attic air temperatures over the 2002 summer period.

Results show that the sealed attic provides a much lower overall mean attic temperatures (79.9°F) as compared with the standard ventilated attic (90.9°F). The average daily summer peak temperature is much lower as the peak ventilated attic reaches 121.1°F on the typical summer day against only 88.0°F in the sealed attic case. This means that the sealed attic system with ducts in the attic as are commonly the case in Florida will suffer less duct system heat gains and impact from return air leakage from the attic zone.

Ceiling Heat Flux

Figure 4 shows the ceiling heat fluxes over the 2000 summer period. The uninsulated ceiling of the double roof with sealed attic (Cell #2) has a peak heat flux greater that of the control (Cell #5), although with a significant time lag of over 3 hours. The mean heat flux for the sealed attic is 1.40 Btu/ft^2/hr, or 40% higher than the control.

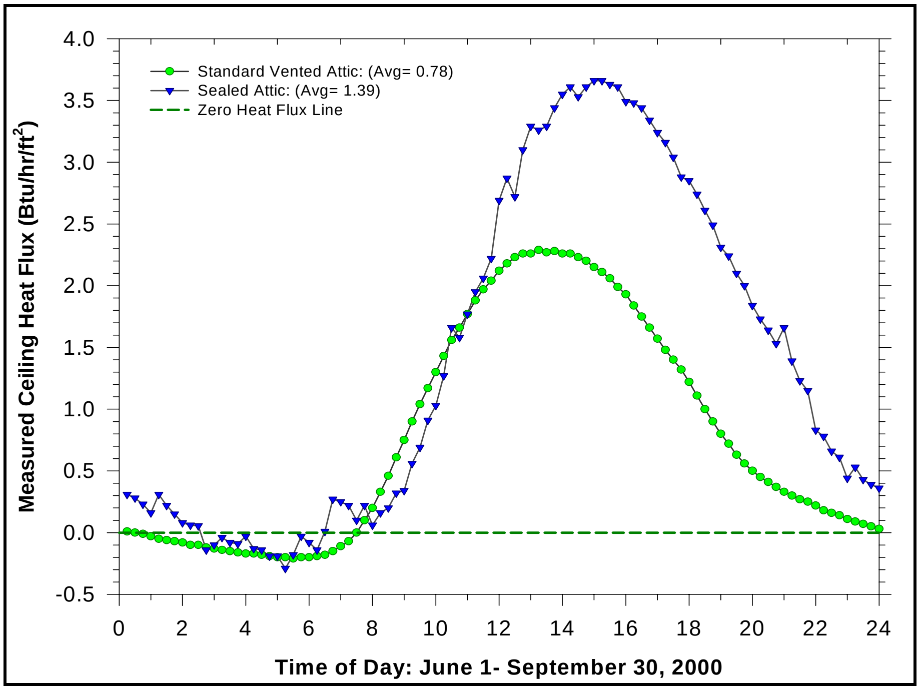

Figure 4. Measured average ceiling heat flux over the summer of 2002.

<u>Estimation of Overall Impact of Roofing System</u>

The impact of a roofing system on cooling energy use in Florida is typically made up of three elements:

- Ceiling heat flux to the interior
- Heat gain to the duct system located in the attic space
- Air unintentionally drawn from the attic into conditioned space

The heat flux through the ceiling impacts the interior temperature and hence the thermostat which then calls for mechanical cooling. Thus, the heat flux impacts cooling energy use at all hours and affects the demand for air conditioning.

The other two influences, air leakage drawn from the attic into the conditioned space and heat gain to the duct system primarily occur only when the cooling system operates. Thus, the impact depends on the air conditioner runtime in a particular time interval. To obtain the average cooling system runtime, we used a large set of residential cooling energy use data which has only recently been made public domain. This data comes from 171 homes monitored in the Central Florida area where the 15-minute air conditioner power was measured for over a year (Parker, 2002).

For each site, the maximum demand during summer was also recorded to determine the maximum cooling system power. Thus, it is possible to determine the diversified runtime fraction by dividing the average air conditioner system power by its maximum demand. This calculation was made by averaging the air conditioner and air handler power for all sites and dividing by the average maximum summer demand, which was 3.96 kW.

Figure 5 shows the maximum average cooling system runtime is approximately 55% at 4 PM and is at its minimum of 15% at 6 AM. It is important to note that this is an average summer day as determined by evaluating all data from June - September inclusive. It does not represent an extreme summer day condition.

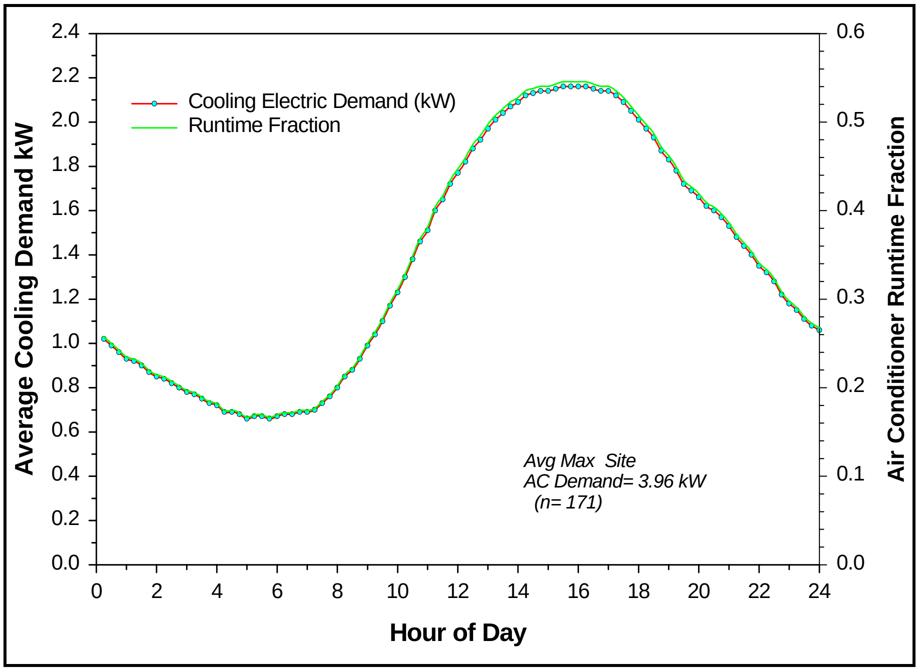

Figure 5. Average air conditioner power and average runtime fraction over an average summer day in a large sample of Central Florida homes.

With the runtime fraction determined for an average home in Central Florida for the summer, it is then possible to estimate the impact of duct heat gain and attic return air leakage with some working assumptions.

To estimate the overall impact for the sealed attic and ventilated attic roofing system, we first assume a typical single-story home with 2,000 square feet of conditioned floor area. Then three equations are defined to estimate the individual impacts of duct heat gain (Q_{duct}), attic air leakage to conditioned space (Q_{leak}) and ceiling heat flux ($Q_{ceiling}$).

For duct gains, heat transfer is estimated to be:

$$Q_{duct} = (Area_{duct}/R_{duct}) * (T_{attic} - T_{duct,air}) * RTF$$

Where:

Q_{duct} = cooling load related to duct gains (Btu/hr)

$Area_{duct}$ = 25% of conditioned floor area or 500 ft^2 (Gu et al., 1996, see Appendix G)

R_{duct} = R-6 flex duct

T_{attic}	=	attic air temperature measured in FRF test cells
$T_{duct, air}$	=	typical air temperature leaving evaporator (58°F)
RTF	=	typical air conditioner runtime fraction as determined from data in Figure 7

Generally, the duct heat gains will favor the sealed attic construction which results in lower surrounding attic temperatures. For attic air leakage to conditioned space, the estimated heat transfer is:

$$Q_{leak} = Flow * PctLeak * PctAttic * 1.08 * (T_{attic} - T_{interior}) * RTF$$

Where:

Q_{leak}	=	cooling load related to unintentional air leakage to conditioned space from attic (Btu/hr)
Flow	=	air handler flow; 4-ton system for 2000 ft^2 home, 400 cfm/ton = 1600 cfm
PctLeak	=	duct leakage assumed as 10% of air handler flow
1.08	=	air specific heat density product per CFM (Btu/hr CFM °F)
PctAttic	=	33% of duct leakage is assumed to be leakage from the attic (see Figure 1)
T_{attic}	=	attic air temperature measured in FRF test cells
$T_{interior}$	=	interior cooling temperature (75°F)
RTF	=	typical air conditioner runtime fraction from data in Figure 7

Heat flux is proportional to the house ceiling area. It will be less advantageous to the sealed attic construction since the attic floor sheetrock is uninsulated. This can be estimated as:

$$Q_{ceiling} = Area_{ceiling} * Q_{flux}$$

Where:

$Area_{ceiling}$	=	2,000 ft^2
Q_{flux}	=	measured ceiling heat flux from FRF data

So the total heat gain impact of a roofing systems is estimated to be:

$$Q_{tot} = Q_{duct} + Q_{leak} + Q_{ceiling}$$

Figure 6 shows the combined roofing system heat gain estimated for 2,000 square foot houses with each of the two roofing systems tested in the summer of 2000. Figure 7 breaks down the Q_{duct}, Q_{leak} and $Q_{ceiling}$ components of Cell #5 control roof to show the relative contribution of each component. Note that the combined estimated duct leak gain and duct conduction gain is approximately equal to the ceiling flux gain.

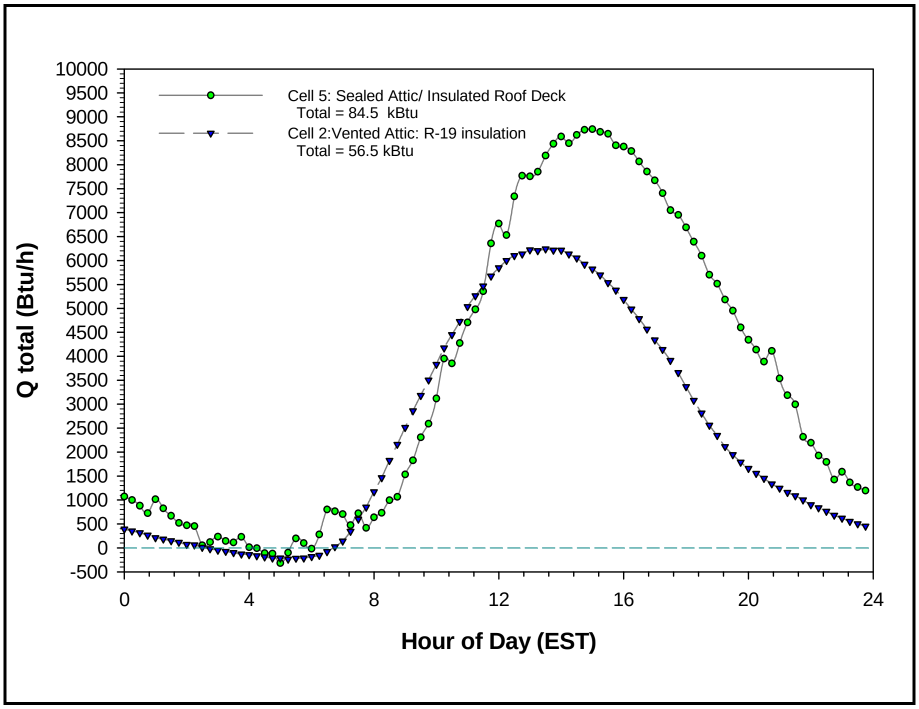

Figure 6. Estimated combined impact of duct heat gain, air leakage from the attic to conditioned space and ceiling het flux on space cooling needs on an average summer day in a 2,000 ft^2 home.

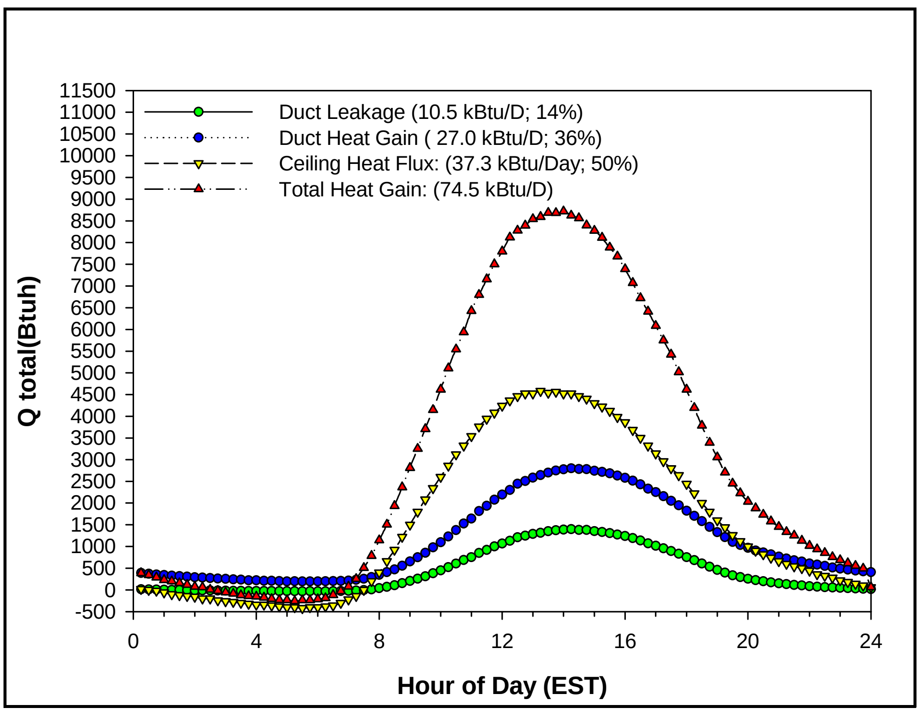

Figure 7. Components of estimated daily heat gain due to duct heat gain, air leakage from the attic to the conditioned space and ceiling heat flux for Cell #5.

The sealed attic with an insulated roof deck is predicted to use slightly more energy than the standard ventilated attic. The is directly a result of the much greater measured heat flux across the uninsulated ceiling.

Sealed Attic with a Ventilated Double Roof

In the summer of 2002, we tested again the sealed attic construction in test cell#2 as compared with the standard ventilated attic (1:300 ventilation). However, this time, we added a second roof suspended above the existing plywood roof decking with a one inch air gap and soffit and ridge vents separating it from the upper roofing section. This is similar to the system recommended by the Asphalt Roofing Manufacturer's Association in their technical bulletin "*Application of Asphalt Shingles Over Insulation or Insulated Roof Decks*," (ARMA, 1995) reproduced as Appendix B in this report. This allows shingle roofs to be ventilated with used with insulated roof decks and sealed attic construction.

As before, data was taken on the new system for the entire summer of 2002 with the double roof, sealed attic system compared with the standard ventilated attic in test cell #5.

Figure 8 shows the sealed attic double roof system (Cell #2) provided the coolest attic space of all systems tested in summer 2002 (average maximum mid-attic temperature was 81.1°F), and therefore also the lowest estimated impact due to return air leakage and duct conduction heat gains. Note that comparison with data taken in 2000 shows that the peak attic temperatures were reduced by about 7°F and that the average was reduced by about 2°F. Whereas a sealed attic without a double roof showed increased cooling loads, a sealed attic with the double roof resulted in better performance than the standard ventilated attic.

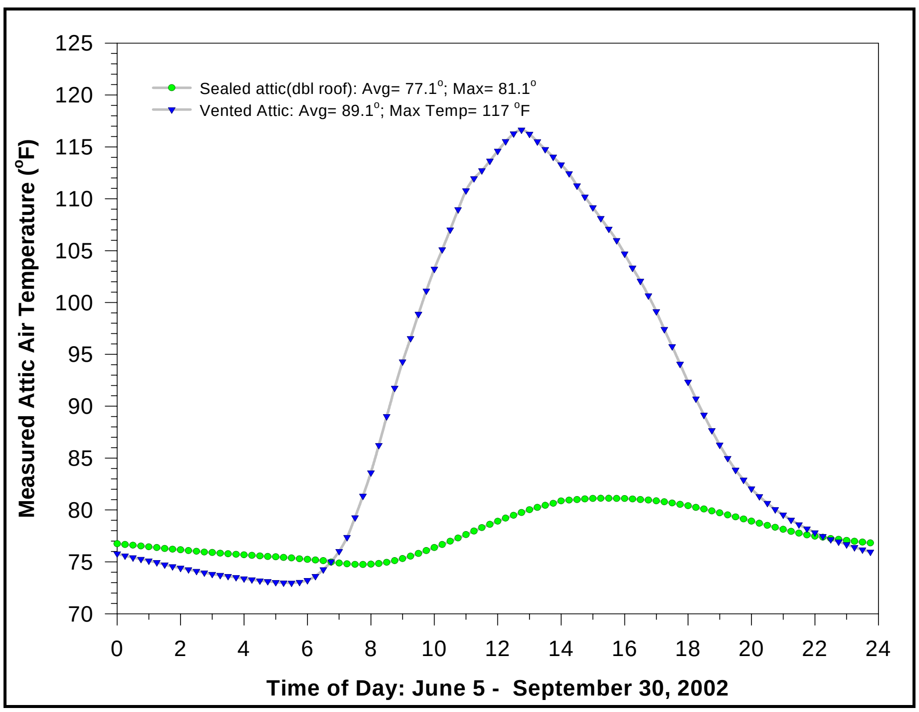

Figure 8. Comparative attic temperatures with standard vented attic vs. sealed attic with double roof.

However, as shown in Figure 9 it still had a higher ceiling heat flux than the ventilated attic, reducing its improvement over the standard black shingle roof. Using the same estimation procedure previously described, it had the most modest reduction in space cooling at only 7% relative to the standard roof. However, note that the addition of the second roof results in large improvement relative to the conventional system without the added ventilation (compare Figure 6 and Figure 10). The conventional sealed attic with the insulated roof deck shows a 13% indicated increase to the cooling load as opposed to a 7% reduction in the cooling load with the double roof. Thus, the ARMA recommended double roof configuration for sealed attics results in large improvements in thermal performance.

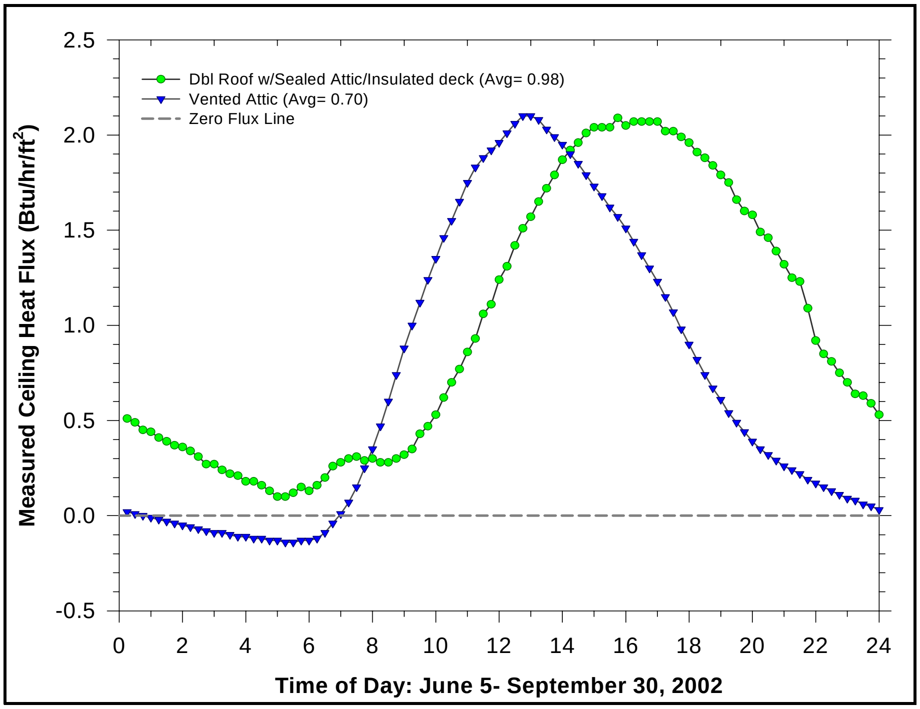

Figure 4. Comparative heat fluxes with standard vented attic vs. sealed attic with double roof.

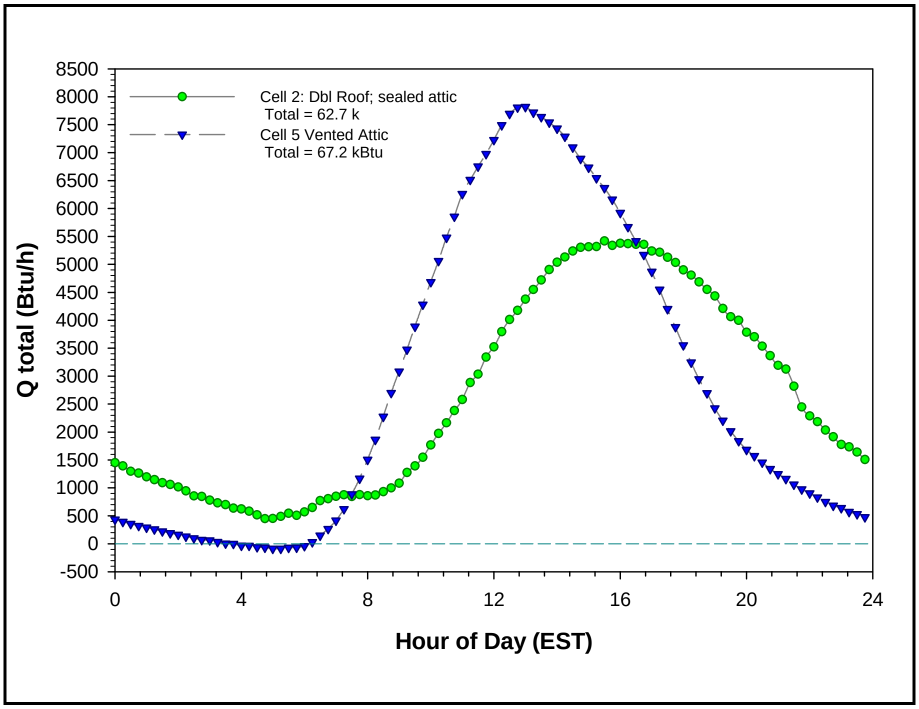

Figure 10. Comparative total roof related heat gain with standard vented attic vs. sealed attic with double roof.

Measured Impacts on Shingle Temperatures

Extensive performance data are measured and collected at the FRF. The data acquisition systems at the FRF poll each measurement station once each 30 seconds. These data are then averaged for each 15 minute period and then transferred on a daily basis to FSEC's centralized data repository where they are stored and may be accessed for analysis. Thus, each single measurement stored in the database is actually the average of approximately 30 individual measurements taken during the previous 15-minute period.

The following graphs and plots provide the data on shingle temperatures for sealed attics with insulated roof decks and conventional vented attics for the summer 2000 roof/attic performance tests. These data are followed by similar FRF measurements made on conventional, ventilated attics with black versus white composition shingles in 1989.

Each 15-minute data point is the average at that time of the day for the entire 3-month period (~90 days). Thus, it can be said that this plot provides the shingle temperature data for the "typical" summer day. As seen in Figure 11, sealed attic shingles get hotter during the day and stay cooler during the night than the shingles on the conventional, vented attic. On average, the shingles on a sealed attic roof will be 1.3°F hotter than on a ventilated attic although the differences are highest at mid-day under solar heating as discussed below. The difference in the peak shingle temperature is roughly ten times the average difference

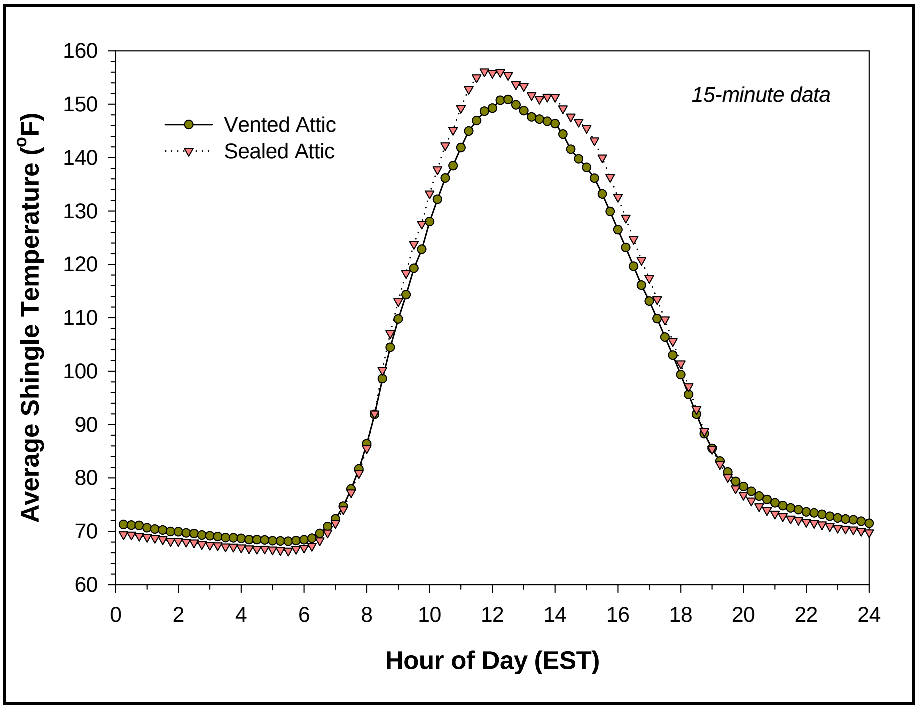

Figure 11. Data on 15-minute average shingle temperatures at FRF over the summer of 2000 in Cocoa, Florida.

Figure 12 describes the typical daily profile of observed shingle temperature differences. Note that on the average summer day, the shingles on the sealed attic are about two degrees cooler than the vented attic at night. Thus, they are also more often below the dew point temperature of the outdoor air and condense more moisture on the roof than the vented attic. Conversely, during the daytime, the shingles on the sealed attic are clearly hotter. The maximum difference is 8.6°F at 12:15 p.m. standard time (1:15 p.m. daylight time). Note the temperature difference inflection between 7:30 and 8:00 a.m. standard time. This inflection, is evidence that there is likely a greater concentration of surface moisture (dew) on the sealed attic shingles than on the vented attic shingles.

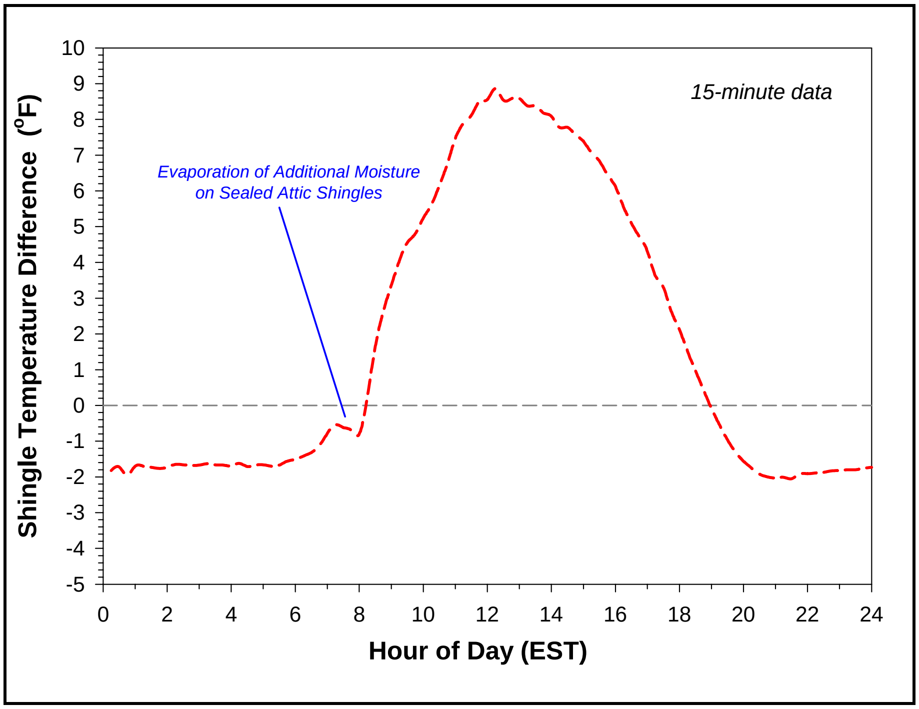

Figure 12. Plot showing the difference between shingle temperatures for a sealed vs. vented attic over the summer of 2000.

Figure 13 shows a regression line is fit to the data, with 95% confidence intervals shown for the prediction. The regression indicates that if the shingle temperature of the vented attic was 160°F on a hot summer afternoon, the temperature of the shingles with the insulated roof deck and sealed attic could be expected to be 9.9°F hotter (170°F). This also does not appear to be a short duration event – note the large number of 15-minute periods where the temperature of the vented attic shingles are 160°F or greater.

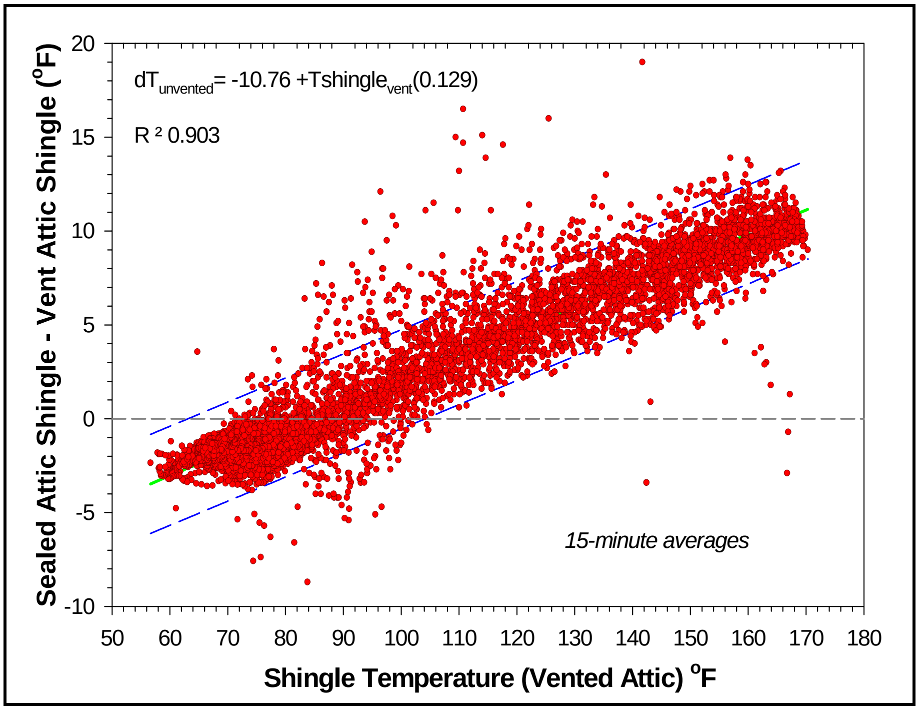

Figure 13. Scatter plot showing the difference between the shingle temperatures over the entire summer plotted against the temperature of the shingles on the vented attic.

The histogram in Figure 14 shows the large difference in the number of 15 minute periods in which the sealed attic shingles are between 170° and 180° as compared with the vented attic cell. Also note that the larger number of instances when the sealed attic shingles are in the 50° and 60°F degree bins. This occurs during evening hours when radiation to the night sky causes the shingle surface temperature of the insulated roof deck to fall to lower temperatures than it otherwise would under a vented configuration. Given the summer dew point temperatures in Central Florida, this suggests that the shingle surface of the sealed attic is more often wet with condensed moisture than that of the vented attic configuration.

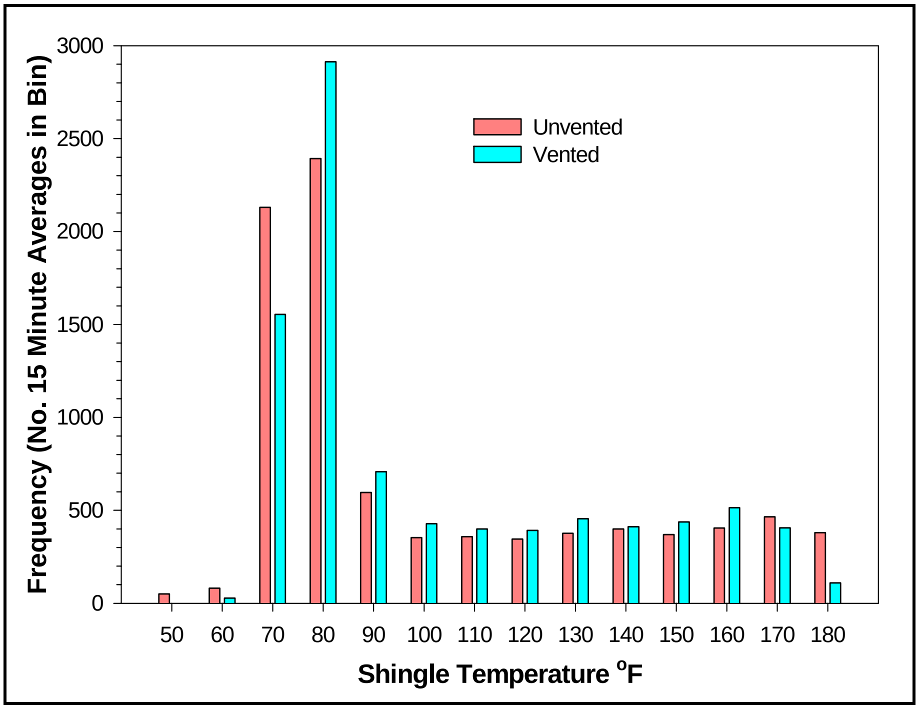

Figure 14. This histogram shows the comparative shingle temperature frequency distributions for the two test cells over the summer of 2000 with temperature bins of 10°F.

The most common observation in Figure 15 showed no difference in shingle temperatures (272 hours). However, the second most common frequency was the instance where the sealed attic shingles were 10°F hotter than the vented attic shingles (103.5 hours).

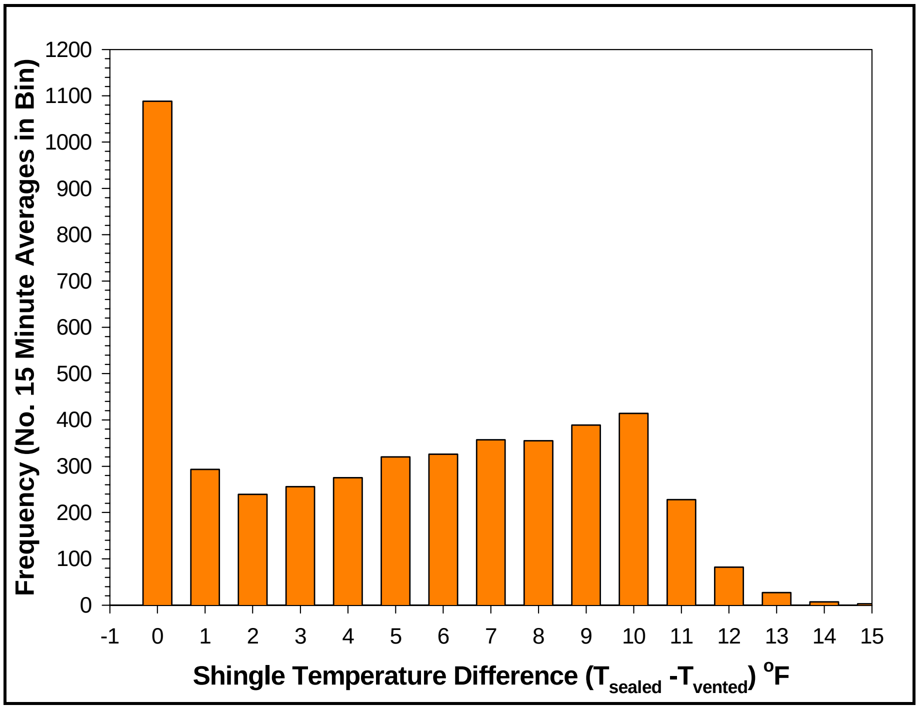

Figure 15. This histogram shows a frequency distribution of the positive, 1°F temperature differences between the shingle temperatures of the sealed and vented attics in the summer of 2000.

The properties of the open cell foam used for these tests are as follows: R-value = 3.6 hAft2A°F/Btu per inch as measured in accordance with ASTM Standard C-518; water vapor permeability = 10-16 perms as measured in accordance with ASTM Standard E-96; air permeability = 0.0049-0.0080 l/sAm^2 @75 Pa in accordance with ASTM Standard E-283.

<u>Temperatures from Conventional Ventilated Attics with Black and White Composition Shingles</u>

Results reported below are from a series of tests conducted at the FSEC Flexible Roof Facility during summer 1989.

The data in Figure 15 are derived in the same manner as those shown in Figure 12. Also note that the average daily peak temperature for the black shingles over the conventional, vented attic occurs at nearly the same time is of virtually the same magnitude in both figures, even though they are measured during different years.

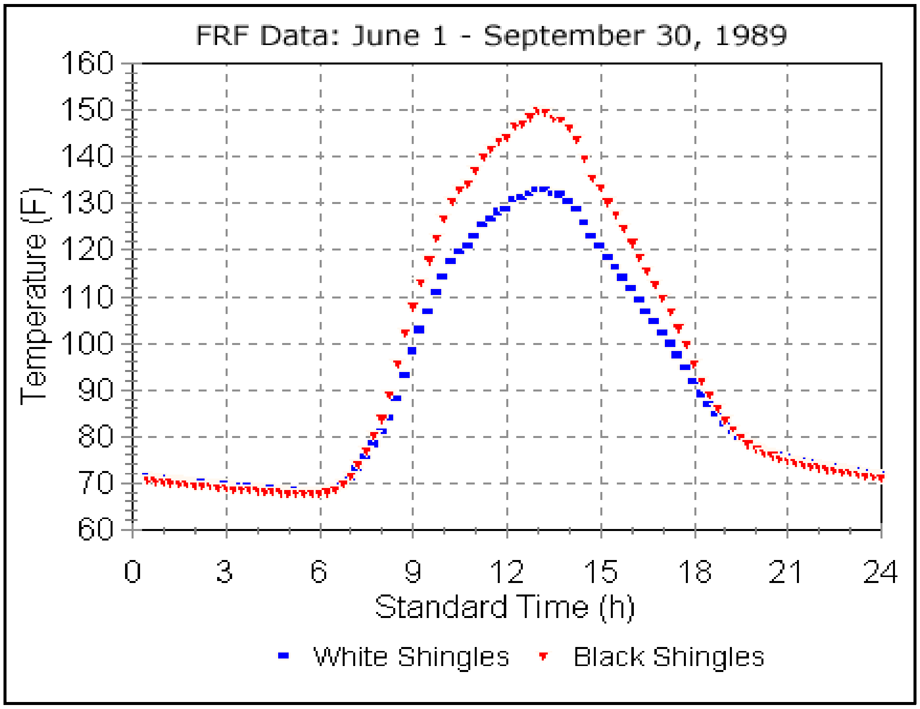

Figure 16. This plot shows the average daily temperature profile shingle temperatures for white and black shingles applied to decking over conventional ventilated attics.

Figure 17 like Figure 13 shows the difference in the average daily temperature profile for the black minus the white shingle temperatures. Note that while the peak temperature difference in Figure 13 is 8.6°F, the peak difference here is 16.4°F.

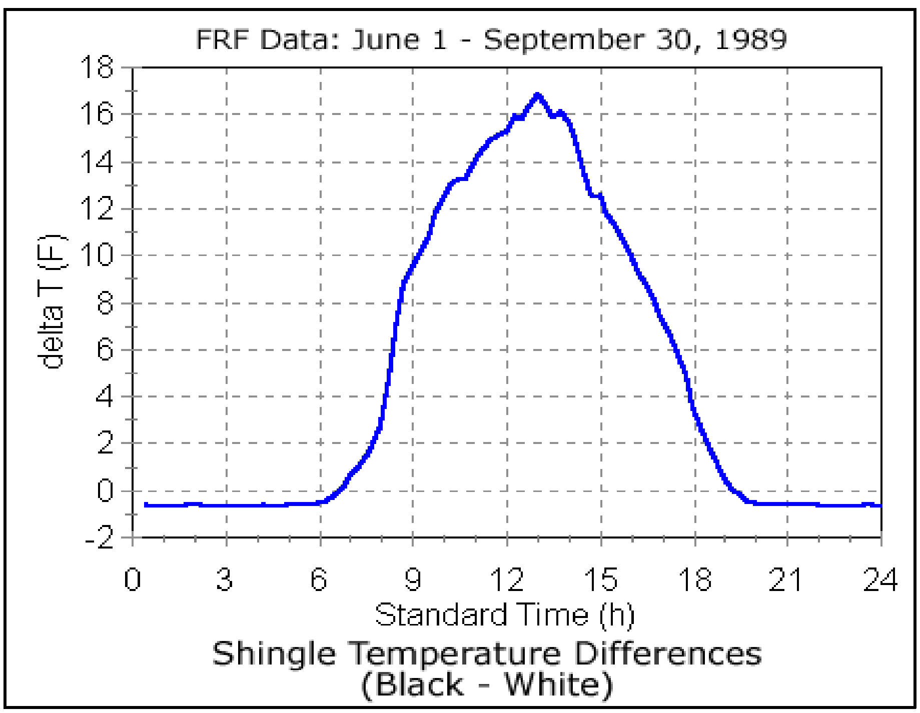

Figure 17. Average shingle temperature differences between black and white shingles applied to decking over conventional ventilated attics.

Figure 18 analogous to Figure 14 this scatter plot shows the difference between the black and white shingle temperatures over the entire summer plotted against the temperature of the black shingles. A regression line is fit to the data. The correlation coefficient for the fit is quite good at $R^2 = 0.95$. The regressions equation indicates that if the temperature of the black shingles was 170°F on a hot summer afternoon, the temperature of the white shingle would be expected to be 21.3°F cooler (170°F).

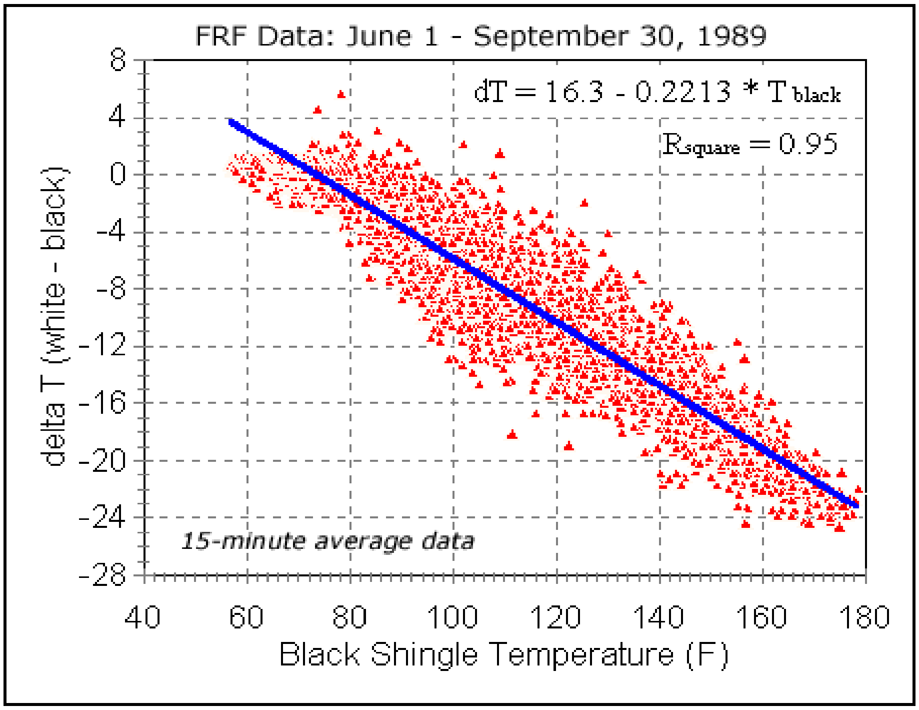

Figure 18. Temperature differences between black and white shingles over the reference black shingle temperatures.

Figure 19 uses these regression analysis results to present a combination view of the shingle temperature difference that could be expected for sealed attics with black shingles and vented attics with white shingles both as compared with vented attics with black shingles. This plot describes in graphic format the expected full range of average shingle temperature differences that might be expected to occur among composition shingles as a function of the temperature of black shingles on a conventional, ventilated attic.

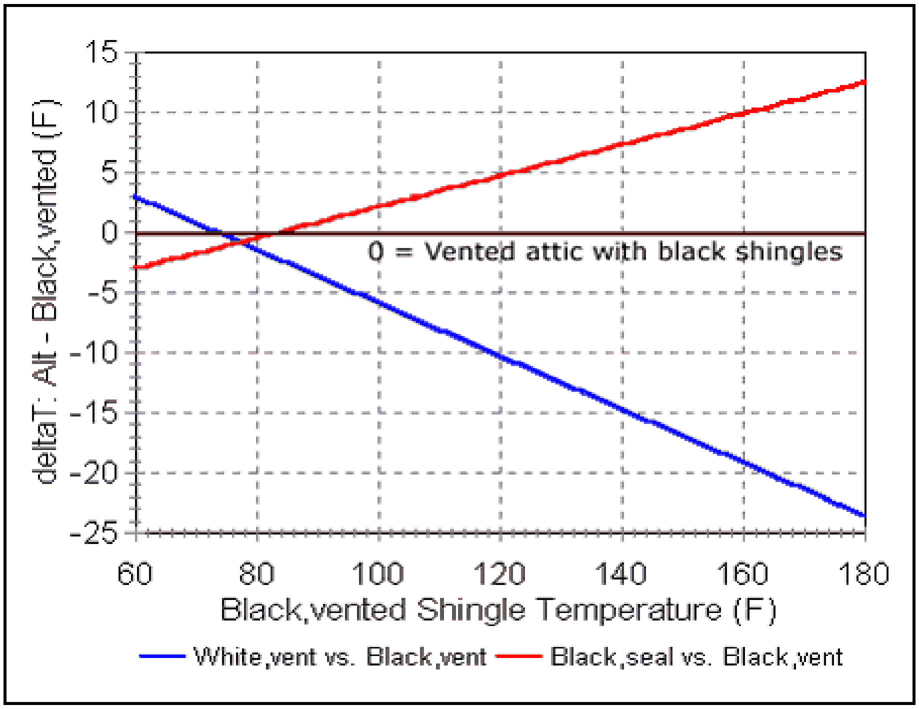

Figure 19. Plot of regression lines between white and black shingles over the temperature of the black shingle reference case.

Key conclusions from the above data:

1) A sealed attic results in shingle temperatures that average about 1.3°F hotter over the summer season. Although this sounds of small consequence, roofing analysts indicate that such increases have some impact on roof longevity (Cash and Lyon, 2002; Roodvoets, 2001).

2) The difference in shingle temperatures produced by different colors is larger than that produced by having a sealed attic with an insulated roof deck. For instance, the sealed attic with decking insulation increased shingle temperatures by a maximum of 8.6°F whereas the increase of black vs. white shingles was 16.4°F. By way of comparison, note that radiant barrier systems create increases in peak shingle temperatures of about 5°F (Parker and Sherwin, 1998).

3) While maximum shingle temperature differences were about 9°F, the difference in the roof decking temperatures under the two roofs was 23°F (166° vs. 143°F) – a large difference. This indicates a much greater temperature amplitude for the decking to which the shingles are applied than for the shingles themselves.

Full Scale Testing of a Sealed Attic in Ft. Myers Florida

The Florida Power and Light Company and the Florida Solar Energy Center instrumented six side-by-side Habitat homes in Ft. Myers, Florida with identical floor plans and orientation, R-19 ceiling insulation, but with different roofing systems designed to reduce attic heat gain. A seventh house had an unvented attic with insulation on the underside of the roof deck rather than the ceiling:

- (RGS) Standard dark shingles (control home)
- (RWB) White "Barrel" S-tile roof
- (RWS) Light colored shingles
- (RWF) White flat tile roof
- (RTB) Terra cotta S-tile roof
- (RWM) White metal roof
- (RSL) Standard dark shingles with sealed attic and R-19 roof deck insulation

Building thermal conditions and air conditioning power usage were obtained. The attic temperature during the peak summer hour is 40^{o}F greater than ambient air temperature in the control home while no greater than ambient with highly reflective roofing systems. Light colored shingles and terra cotta roofs show temperatures in between those extremes.

Measurements showed that the three white reflective roofs would reduce cooling energy consumption by 18-26% and peak demand by 28-35%. The terra cotta tile roofs and white shingles would produce cooling savings of 3-9% and 3-5%. The sealed attic construction with an insulated roof deck was shown to produce energy use reductions of 6-11%.

Sealed Attic Construction RSL

The seventh house (RSL) tested the sealed attic approach to residential insulation: an attic completely sealed and with a spray foam insulation applied to the underside of the roof decking in place of conventional blown or batt insulation.

Figure 20. Sealed attic home under construction in Ft. Myers, FL. Conventional dark gray shingles were used.

Figure 21. Insulating foam being applied to a 5-inch depth on the under side of the roof.

As described earlier, a potential disadvantage is that the roof insulation can result in significantly higher decking and roof surface temperatures. Also, the insulation at the roof deck has a more difficult task since it is working against 170^{o} (temperature of roofing) rather than 130^{o} (temperature on top of insulation in a conventional attic at summer peak). The ducts are exposed to less heat gain, but building heat transfer surface areas are increased relative to the conventional case.

The roofing system on the RSL home was identical to that in the control home, dark gray composition shingles over roofing felt and decking. The external appearance was like the conventional homes, however foam insulation was used in the roof deck rather than cellulose insulation in the ceiling assembly. The attic floor consisted solely of rafter and ½ inch gypsum board. The roof deck of the RSL was covered with 5 inches of insulating foam. Application thickness was targeted to achieve an R-19 application – similar in thermal resistance to the cellulose insulation in the other homes. The installed product is a semi-rigid polyurethane foam insulation with a nominal density of 0.45 - 0.5 lbs/ft^3 and an R-value of 3.81 ft^2-hr- ^{o}F/Btu/inch. The product also claims to help improve air sealing of the home by controlling leakage from building joints.

Results over the Monitoring Period for FPL Project

The relative performance of the homes over the entire unoccupied monitoring period was evaluated. The five figures below (Figures 22-26) show the fundamental impacts of the roofing system on cooling energy consumption over the entire unoccupied monitoring period from July 8th - July 31st, 2000.

Figure 22 depicts the ambient average air temperature and solar conditions over the entire unoccupied period. Figures 23, 24 and 25 show the thermal influences of the roofing system. The first plot graphs the average roof surface temperature over the daily cycle. The second plot shows the corresponding temperature at the underside of the roof decking surface. Note that the roof surface temperature and decking temperature are highest with the sealed attic construction since the insulation under the decking forces much of the collected solar heat to migrate back out through the shingles. On average the shingles reach a peak temperature that is seven degrees hotter than standard construction. However, decking temperatures run almost 20^{o}F hotter. The white roofing systems (RWM, RWF and RWB) experience peak surface temperatures approximately 20^{o}F lower than darker shingles. The terra cotta barrel tile case runs about 10^{o} cooler.

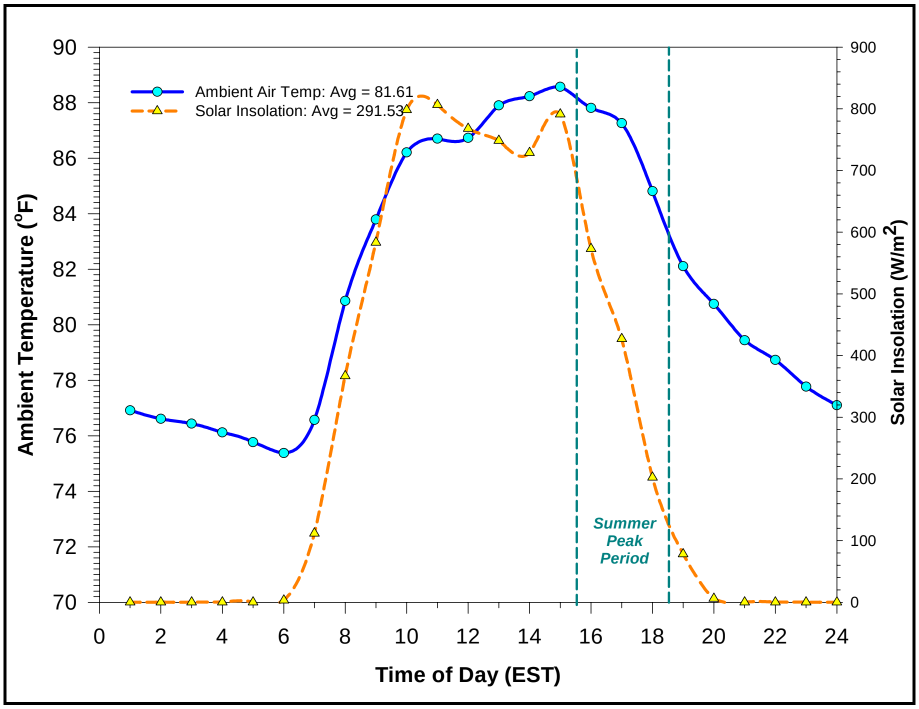

Figure 22. Average ambient air temperature and solar irradiance over the unoccupied period.

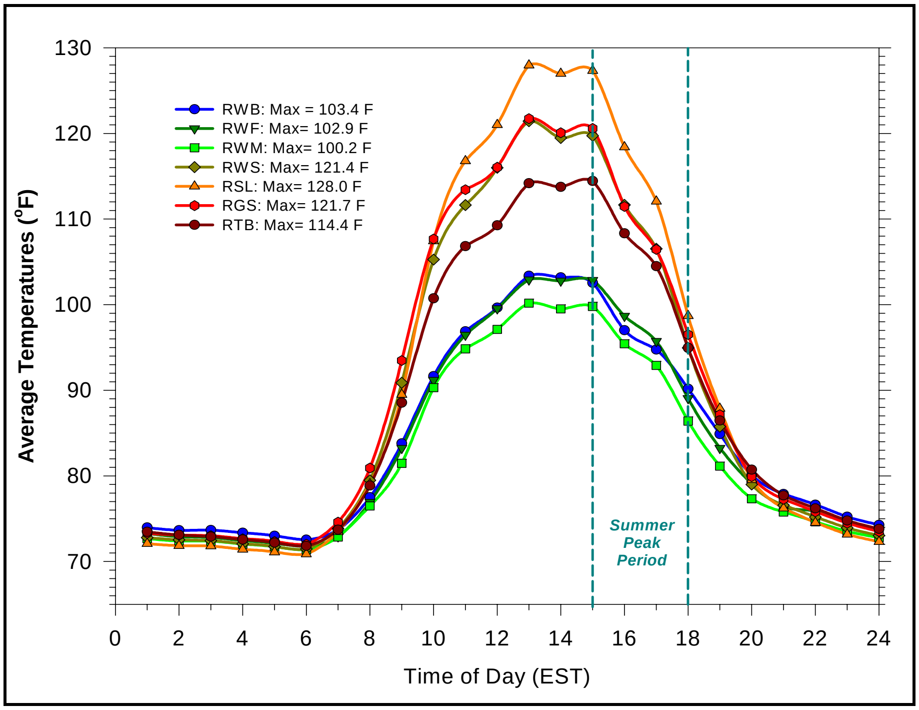

Figure 23. Average roof surface temperature profiles over the unoccupied period.

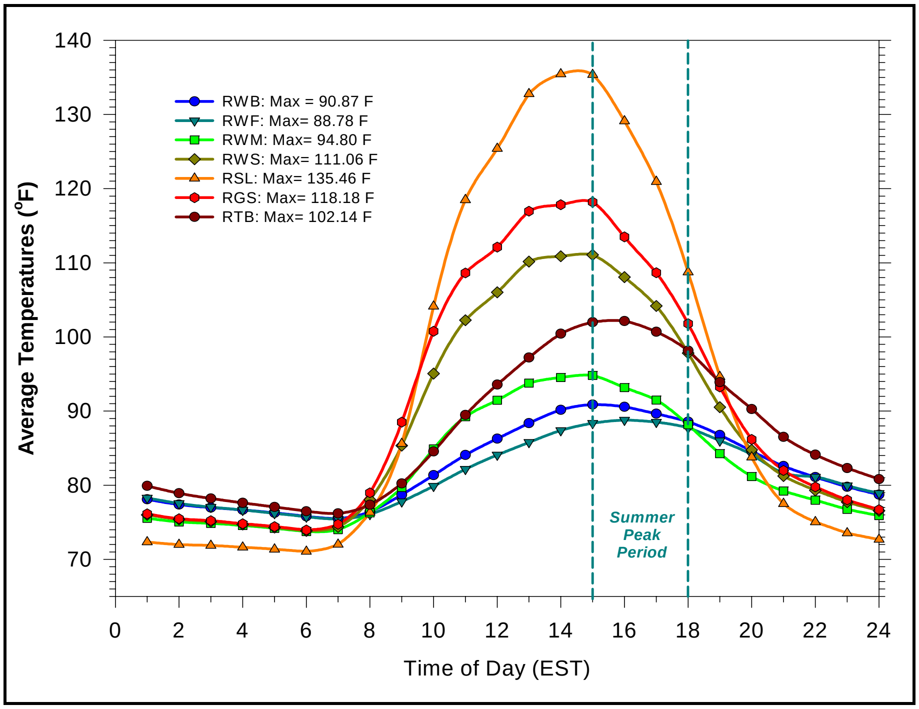

Figure 24. Average roof decking surface temperature profiles over the unoccupied period.

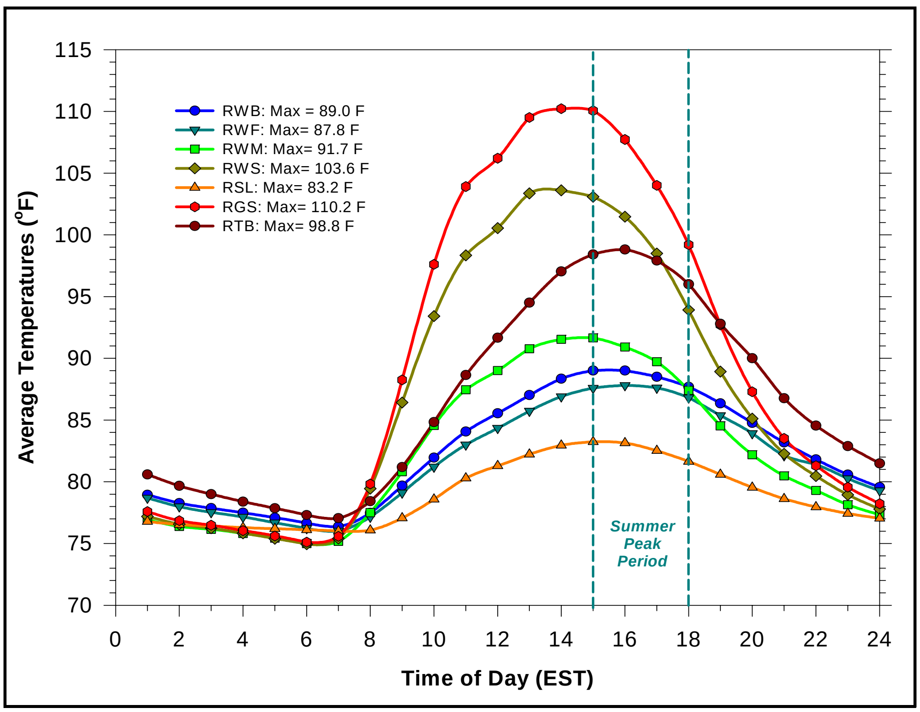

Figure 25. Average attic air temperature profiles over the unoccupied period.

The measured mid attic air temperatures (Figure 25) above the ceiling insulation revealed the impact of white reflective roofs with average peak temperatures approximately 20° cooler than at the control home. Whereas the attic in the control home reaches 110°F on the typical day, the attics with the highly reflective white roofing materials only rise to about 90°F.

As expected, the home with the sealed attic had the lowest attic temperatures reaching a maximum of 83ºF compared with the 77ºF being maintained inside. However, the sealed attic case has no insulation on the ceiling floor with only studs and sheet rock. Thus, from a cooling loads perspective, the low attic temperature with this construction is deceptive as the space is unintentionally cooled. Since ½ inch sheet rock only has a thermal resistance of 0.45 hr-ft^2-ºF/Btu, a significant level of heat transfer takes place across the uninsulated ceiling. *While this construction method reduced attic air temperatures, it did not reduce ceiling heat transfer as well as other options.* Ceiling heat fluxes are actually higher. In this case, the ceiling and duct system is unintentionally cooling the attic space which can lead to the false impression that roof/attic loads are lower.

Figure 26 summarizes the measured cooling load profiles for the seven homes over the unoccupied monitoring period. Not surprisingly, the control home has the highest consumption (17.0 kWh/day). The home with the terra cotta barrel tile has a slightly lower use (16.2 kWh/day) for a 5% cooling energy reduction. Next is the home with the white shingles (15.6 kWh/day) – an 8% reduction. *The sealed attic comes in with a 12% cooling energy reduction (14.9 kWh/day).*

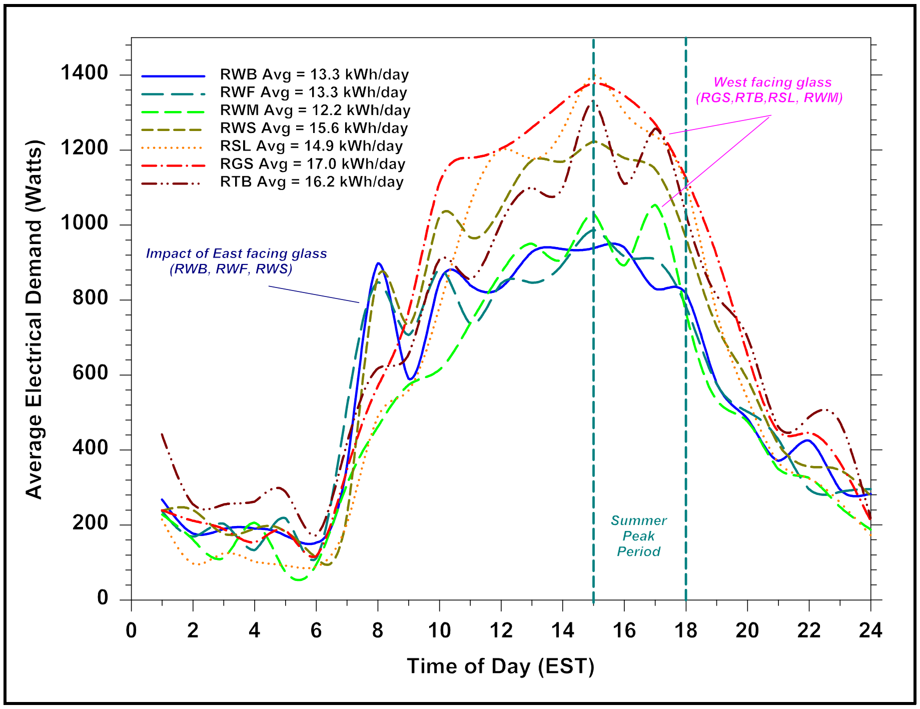

Figure 26. Average space cooling energy demand profiles over the unoccupied period.

The true white roofing types (> 60% reflectance) clearly show their advantage. Both the white barrel and white flat tile roofs averaged a consumption of 13.3 kWh/day or a 22% cooling energy reduction, while the white metal roof shows the largest impact with a 12.2 kWh/day August consumption for a 28% reduction. The numbers in Table 3 are adjusted to account for differences in interior temperature and AC performance. **The performance of the sealed attic case, presented in bold showed an overall cooling energy reduction of 8%.**

Table 3
Cooling Performance During Unoccupied Period
July 8th - 31st, 2000

Site	Total kWh	Savings kWh	Save %	Thermo-stat	Avg. Attic ºF	Max. Attic ºF	Temp. Adjust. %	Adjust Sav. %	Field EER	Final Sav. %
RGS	17.03	0.00	0.0	77.1º	90.8	135.6	0.0	0.0	8.30	0.0
RWS	15.29	1.74	10.2	77.0º	88.0	123.5	-1.2	11.4	9.06	10.6
RSL	**14.73**	**2.30**	**13.5**	**77.7º**	**79.0**	**87.5**	**5.4**	**8.1**	**8.52**	**7.8**
RTB	16.02	1.01	5.9	76.7º	87.2	110.5	-1.6	7.5	8.12	7.7
RWB	13.32	3.71	21.8	77.4º	82.7	95.6	2.8	19.0	8.49	18.5
RWF	13.20	3.83	22.5	77.4º	82.2	93.3	2.1	20.4	7.92	21.5
RWM	12.03	5.00	29.4	77.6º	82.9	100.7	4.9	24.5	8.42	24.0

Influences of Sealed Attic Construction on Water Damage and Storm Resistance

Previous investigations in the wake of several hurricanes, done by the U.S. Department of Housing and Urban Development has show that for steep roof systems, many roofing failures occurred at the ridge or gable ends where wind-induced forces were the highest. For low-slope roof systems, damage occurred primarily at roof corners (Chiu et al., 1994). Gable-ended construction also appears particularly problematic (Vickery, 2002). Keith (1994) observed that the most common type of structural damage from Hurricane Andrew in Florida was loss of gable-end walls.

Also, within this same empirical data, ventilated attics showed considerable sheathing uplift during hurricane events—potentially leading to roof failure—particularly when ridge vents are not provided (soffit venting only) (Cook, 1994). FEMA (1993). However, there is no study to compare performance for various attic types under hurricane wind conditions.

When wind speed reaches hurricane level, the vented attic has not only much higher ventilation rate, but also much higher moisture intrusion due to horizontal wind-driven rain, in addition to high pressure on the roof surface. In contrast to the vented attic, the sealed attic only need to endure wind pressure on the roof surface without moisture intrusion.

The reality of the differences associated with water intrusion in vented attics were dramatically emphasized during recent Hurricane Frances and Jeanne in the late summer of 2004. Two consulted Florida builders who build homes with both sealed attic and ventilated attic construction reported that while they experienced no water intrusion problems with sealed attics, those with off-ridge ‘scoop’ or ‘gooseneck’ vents did experience problems. *Fallman Design & Construction* (Fallman, 2005) reported no water intrusion with his three sealed attic homes while they experienced three call backs with ceiling moisture damage from leaking off-ridge vents that were facing east during Hurricane Jeanne out of approximately 45 new homes in the Clermont, Florida area. Also a recent request for the Florida Homebuilder’s Association found evidence of high-wind rain water intrusion through soffit eaves (Lstiburek, 2005). As example, one large Melbourne, FL builder, *Mercedes Homes*, reported common problems with water intrusion into soffits and thru walls during recent hurricanes (Baric, 2005). While specific test methods are available to reduce the incidence of rain intrusion from ridge and soffit vents, (TASS 100), the requirements are either being ignored in construction, or the test methods are not mirroring the actual storm conditions seen, particularly in two-story residences (Lstiburek, 2005).

In the past there has been some question about how vapor permeable foamed decking insulation may be. If vapor impermeable, such a situation could lead to roof decking and even truss deterioration.. There is also the issue of how readily water leaks would come through a foamed in roof deck and how leaks would be located. While factory representatives have claimed the product is permeable, experiments conducted at FSEC (Moyer 2005) have not verified immediate liquid water transport. However, some field information on this issues comes from *Baily Engineering Corporation* in Palm Beach Gardens. This company received call back from four homes with leaking ridge vents and three others from homes with off-ridge scoop vents (Baily, 2005). All sustained ceiling water damage. However, the one home with sealed attic construction had a large tree fall on the house which resulted in one larger six inch hole and two smaller roofing punctures. Even with the smaller holes, the water came down through the *Icynene* roof insulation product with the leakage site easily located and repaired.

While there are yet no empirical studies of the impact of sealed attic construction on hurricane resistance, evaluation on an engineering basis would suggest two major ways in which a sealed roofing system may be superior.

- The sealed roof would not have soffit and ridge vents which would produce sheathing uplift as in a ventilated attic. This comparative benefit relative to a vented attic can be assessed either empirically with very expensive full scale wind tunnel test or with less expensive CFD modeling. Although proposed, this potential impact not yet been evaluated. However, Visscher et al., (2004) showed that added attic ventilation led to more rapid destruction of scale model homes in hurricane wind reproducing wind tunnels.[8]

- The foamed insulation on the underside of the roof decking essentially glues all of the sheathing sections together. While, the structure impact of this change has not been accessed (cannot be easily evaluated without destructive testing), it is likely a positive effect.

Advantages of Sealed Attic Construction

Below, we briefly summarize the advantages and disadvantages of sealed attic construction:

1) Attic duct systems and air handlers are essentially brought into the conditioned space within the thermal envelope (Rudd, 2004). This reduces duct conduction losses and the seriousness of duct air leakage for homes with ducts located in attics.

2) Modest energy savings from the above characteristics have been demonstrated in several projects where the ducts were located in attics.

[6] FSEC has recently proposed to the Florida Department of Community Affairs to study how sealed attic construction may create a more hurricane resistant roof. A computational fluid dynamics (CFD) software, FLUENT, would be used as a tool to perform simulations. The possible parameters would consist of roof vent size, location, and soffit size for the vented attic, and attic configuration for both attic types, such as hip roof vs. gable roof. A three dimensional representation will be used based on data showing its importance for modeling of wind uplift. For instance, uplift forces are greatest at the corners of the roof. The flow mechanism responsible for this phenomenon is called roof vortex. Roof vortexes can generate extreme suction peaks along the two leading edges at each roof corner (Tieleman, 1994). Local suction forces can be 2.5 times those on other roof sections (Imbert et al., 1994).

3) Outdoor moisture migration into the attic is reduced, potentially reducing condensation on duct work and air handlers and associated moisture damage.[9]

4) Location of the insulation on the roof plane leaves a clean, semi-conditioned space that is ideal for storage in Florida homes which generally lack this feature (no basements).

5) Sealing of ceiling penetrations is no longer needed or critical (partition wall joints, recessed can lights).

6) Attic vents product (ridge vents, scoop vents, soffit vents) are no longer required, potentially reducing the potential for wind driven rain during storm events.

7) Potential for wind uplift on sheathing may be reduced since the soffit and ridge vents are no longer allowing pressure gradient within the attic.

8) Inspection of insulation thickness and consistency in the attic is more straightforward.

9) Damage to ceiling insulation from installation of ceiling fans, security systems, telephone and communications is no longer an issue as the insulation is on the roof plane.

10) Provides a better place to work if the air handler is located in the attic which would likely lead to better servicing (changing of system filters etc.)

11) Evidence suggests that the sealed attic construction technique leads to a slightly greater building airtightness level. However, larger statistical samples would be required to verify this influence.

12) Due to the duct system being located within the insulated envelope and essentially within the conditioned space, it is possible to down size the air conditioner by approximately 0.5 tons for a typically sized home (ACCA, 2003). Compared to similar roof homes with ducts in the attic.

13) All other things being equal, homes with a sealed attic and roof deck insulation will recover interior temperatures more rapidly than houses with vented attics. This is because heat conduction to attic duct systems is reduced since temperature are not 120°F or more, but rather approximately 85°F under peak summer conditions. This has been predicted by Siegel et al (2000) and also verified by experiments within the FPL project in Ft. Myers (Parker et al., 2000).

Potential Disadvantages of Sealed Attic Construction

1) Expense: the expense of the sealed attic system is generally greater than standard vented attic construction. Typical costs are elevated by approximately $1.00 - $1.50/square foot of conditioned floor space.

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[7] Personal communication with Neal Moyer, January 2005.

2) Sealing of the attic needs to verified by inspection and preferably by testing. At a minimum, potentially qualifying attic construction would not include any of the following: perforated soffit vents or other soffit vents, ridge vents, off ridge vents, gable end vents and powered roof vents.

3) Shingle temperature are elevated by a maximum of 7°F, with typical overall summer increase of 1.3°F. Peak decking temperatures are raised by approximately 23°F. While some researchers maintain that these temperatures are acceptable (TenWolde and Rose, 1998), there is little question that shingle longevity will be reduced. Currently only two shingle manufacturers will warranty their products without attic ventilation. However, while higher temperatures are likely negative, there is little long term data to assess the impact of the temperature differences.

4) Potential for solar driven moisture intrusion with shingle roofs require that a vapor retarder roof underlayment of one perm (water vapor transmission ASTM E-96) be located beneath the shingles rather than the traditional 15 lb felt roofing paper.

5) Consistency of the deck insulation is very important for the thermal and moisture-problem characteristics of the overall system. Thus, foamed insulation thickness (R-19 equivalent) should be inspected and netted and bagged loose fill systems should be avoided. Currently, even those advocating sealed attic system are not recommending netted loose-fill or batt systems in hot humid climates (Rudd, 2005).

6) There are some questions about roof leaks and how they are located and repaired within such system. While anecdotal experiences in the last hurricanes suggest that location of the leaks is no more difficult than with standard systems, much more rigorous research is needed.

7) Sealed attics require a larger area to be insulated (tilted roof planes are larger than the mostly flat ceiling plane) with greater heat loss. Gable ends have to be sealed and insulated also. Heat gains are increased as well as insulation costs.

8) Lack of ventilation increases heat transfer across a given insulation level. This occurs as the temperatures across the insulation are increased as there is no ventilation air to reduce heat build up above the insulation. In homes with ducts below the ceiling, sealed attic of the same insulation will lead to higher cooling bills.

9) Gas combustion appliances located in the attic (e.g., furnace or hot water heater) must be configured for closed combustion or else moved to the garage.

10) It is more difficult to inspect the condition of the sheathing.

11) With typical uncovered foam applications to the roof decking, there is a conflict with fire provisions of the residential Florida building code.

Conclusions

A detailed literature review has been conducted on the issue of attic ventilation in Florida homes and its impact in a number of aspects affecting energy, moisture control, roof longevity, storm resistance and a host of other factors.

The review has also covered the increasingly common construction type, here referred to as sealed attic construction where the attic is not ventilated and the insulation is located on the roof decking, resulting in a semi-conditioned attic and bringing the deck system substantially within the conditioned space.

The following commonalities have emerged from our review:

Energy

E1. Attic ventilation reduces space cooling energy use in typical homes with conventional ceiling insulation by 5% or less.

E2. Sealed attic construction was measured in a realistic test in Ft. Myers, Florida to reduce space cooling by about 8%. Savings are less for very well sealed duct systems and more for poorly sealed ducts. However, savings would be negative if the duct system was otherwise within the conditioned space. No peak energy savings were demonstrated for the technology as ceiling heat fluxes are typically higher during utility peaks.

E3. Other options are available that can produce similar or greater energy savings: radiant barrier systems have been measured to reduce space cooling by an average of 9%. Added ceiling insulation has been shown to provide similar savings. Reflective white roofing systems with ventilated attics can reduce space cooling by an average of 20%.

E4. When combined with more reflective roofing options (light colored tile, metal or shingles), savings from sealed attic construction would be increased considerably

E5. Although manufacturers claim that lower deck insulation can be justified due to air tightness, this does not appear to compensate for the need for at least R-19 deck insulation with sealed attic systems.

E6. Due to the moderate conditions around the duct system, the AC system size may be slightly reduced and servicing of attic air handlers is more straightforward.

E7. As measured by testing at FSEC in 2000 and 2003 , the recommendation of ARMA for shingle roofs with the sealed attic system to use a double roof with a ventilated air space underneath (Appendix B) substantially improves the energy related performance of the system and lowers peak shingle temperatures.

E8. More rigorous testing of the influence of attic ventilation on energy use in conventional construction is recommended and proposed.

Moisture Control

M1. Although the rationale for attic ventilation is for moisture control, this was historically based on needs in cold climates and to prevent ice dams. The justification for attic ventilation for moisture control in hot humid climates is not scientifically defensible.
M2. Ventilated attics can introduce additional moisture loads into Florida homes by allowing moisture laden air in the attic that may communicate with the indoors.
M3. Sealed attics can help to reduce moisture condensation on attic mounted ducts and air handlers by reducing the moisture level of the air around the ducts and on the back side of ceiling drywall when low hermostat set points are used (<75°F).
M4. Sealed attic construction should only be allowed with expanded foam used to insulate the roof decking. Loose fill systems, either netted or friction fit, should not be utilized as air can migrate to the decking underside with water condensation leading to potential for moisture damage. Thermal performance is also compromised within loose fill systems due to the high temperatures so that they are not recommended.
M5. Sealed attic construction when used with shingle products should use a one perm membrane under the shingles rather than standard 15-lb. felt to prevent moisture from being driven into the attic from solar induced vapor pressure.

Roof System Longevity

R1. Attic ventilation results in slightly cooler roof surface temperatures.
R2. Examination of tile roofing systems have shown no large change in roofing system temperatures.
R3. Attic ventilation has less effect on roofing with light colored building materials.
R4. The impact of sealed attic with deck insulation on shingle temperatures (+7°F on peak) is slightly greater than that seen with radiant barriers (+5°).
R5. Peak sheathing temperatures are elevated by about 23°F for sealed attic construction.
R6. Impact of shingle color on temperature is greater than the effect of attic ventilation
R7. The impact of geographic location on shingle temperatures is much greater than that associated with ventilation (Phoenix has higher shingle temperatures than Miami).
R8. One estimate (Cash and Lyons, 2002) showed no attic ventilation would reduce shingle life by less than a year in Miami. Another estimate indicated approximately a 2-year reduction for a 20-year shingle for the same conditions (Roodvoets, 2001).
R9. Sealed attic construction may not pose additional problems to locate roof leaks although long-term experience is lacking.

Hurricane Resistance

H1. Roof and ceiling damage is the most common hurricane associated damage in post hurricane evaluations after numerous storms in the last twenty years.
H2. Older roofing systems failed often – particularly lower quality shingles and mortar set tile.
H3. Evidence suggests that if soffit venting is provided that ridge vents should also be installed to reduce potential for sheathing uplift during high winds.
H4. Considerable evidence was seen that off-ridge vents with a disadvantageous facing will allow rain water intrusion during high wind storms.
H5. Anecdotal evidence of rainwater intrusion into soffits under high winds.

H6. Sealed attic construction may reduce damage from rainwater intrusion in attics.
H7. Sealed attic construction likely has unknown benefits on reducing roofing uplift during storm events. Research is proposed to simulate this influence.
H8. Sealed attic construction has unknown benefits in terms of "gluing" together all sections of the roof sheathing, potentially improving the structural strength.

<u>Other Factors</u>

O1. The importance of proper air sealing of sealed attics for proper function means that such systems should be inspected to insure that attic ventilation products (e.g., soffit, ridge, gable and off-ridge vents) are not installed during construction.
O2. Sealed attic construction may reduce insect and rodent infestation in attics and reduce dirt/dust entering the indoor environment through the attic potential improving IAQ.
O3. Sealed attic construction produces a clean, large semi-conditioned space in the attic that can be useful for storage although trusses can reduce its utility for ease of use.
O4. Reduced heat conduction and return leakage from homes with sealed attic will result in faster "pull down" when AC systems are energized.
O5. Research at the University of California suggests that eliminating soffit and ridge vents will reduce fire spread rates during wildfire events.
O6. Rigorous sealing of ceiling penetrations is no longer required
O7. Sealed attic systems are more expensive due to the greater cost for the expanded foam insulation product for the larger roof plane area. However, some of this cost increase can be avoided by eliminating the expense of ridge and off ridge vents.

Recommendations for Further Research

Relative to the issues raised in this report, FSEC has recommended that two new research studies be undertaken for 2005/2006. The first is to look at attic ventilation in a more comprehensive way using the five test cells of the Flexible Roof Facility. A second research project would use computerized fluid dynamics (CFD) modeling to examine the potential improvement in hurricane resistance created by sealed attic construction. These two proposed projects are described in Appendix C and D of this report.

References

ACCA, 2003. Residential Load Calculation: Manual J 8th Edition, Version 1.2, Air Conditioning Contractors of America, Arlington, VA, 2003.

ASHAE, 2001, Handbook of Fundamentals, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA.

Baily, Ron, 2005. Personal Communication, *Baily Engineering Corporation*, 10 January.

Baric, J., Personal Communication, Mercedes Homes, 28 February 2005.

Beal, D. and S. Chandra, 1995. "The Measured Performance of Tile Roof Systems and Attic Ventilation Strategies in Hot and Humid Climates," Thermal Performance of the Exterior Envelopes of Buildings VI, ASHRAE/DOE/BTECC, December, 1995.

Brenner, R. J. "Insect pests, construction practices and humidity," in E. Bales and W. B. Rose [eds.], Bugs, Mold & Rot: Proceedings of the Moisture Control Workshop, National Institute of Building Sciences, Washington, D. C., pp. 19-26. 1991.

Cash, Carl C., and Lyon, Edward G., 2002. What's the Value of Ventilation? *Professional Roofing*, March, pp. 20-26.

Chiu, Gregory L.F., Perry, Dale C., and Chiu, Arthur N.L., 1994. "Structural Performance in Hurricane Iniki." Proceedings of Seventh United States National Wind Engineering Conference, Volume I, Gary C. Hart, Editor. Washington, D.C., National Science Foundation.

Cook, Ronald A., 1994. "Overview of Hurricane Andrew in South Florida." In *Hurricanes of 1992*, Ronald A. Cook and Mehrdad Soltani, Editors. New York: American Society of Civil Engineers.

DCA, 2004, "Section R314: Foam Plastic," Florida Building Code - Residential, Department of Community Affairs, Tallahassee, FL.

Dejarlais, Andre, 2004. "Comparison of Cathedralized Attics to Conventional Attics: Where and When Do Cathedralized Attics Save Energy and Operating Costs?" Proceedings of the Performance Envelopes of Whole Buildings IX International Conference, December 5-10, 2004, Clearwater Beach, FL

EDU, 2005. "Fiberglass-Insulated Homes are the Leakiest," Energy Design Update, Aspen Publishers, April 2005, p. 10-11.

Fairey, P.W., 1988. "The Measured, Side-by-Side Performance of Attic Radiant Barrier Systems in Hot-Humid Climates," Thermal Conductivity 19, (David W. Yarbrough, ed.), Plenum Press, NY, pp. 481-496.

Fairey, P., M. Swami, and Beal, D., 1988. Radiant Barrier Systems Technology: Task 3 Report, Florida Solar Energy Center, FSEC-CR-211-88, Cape Canaveral, FL.

Fairey, P. and Swami, M., 1988. "Analysis of Radiant Barrier Systems Using Mathematical Model," Proceedings of the Fifth Annual Symposium on Improving Building Energy Efficiency in Hot Humid Climates, Florida Solar Energy Center, FSEC-PR-147-88, Cape Canaveral, FL.

Fallman, Paul, 2005. Personal Communication, *Fallman Design and Construction*, 10 January.

Hedrick, R., 2003. Integrated Design of Residential Ducting and Airflow Systems: Building Homes with Ducts in Conditioned Space. White Salmon: New Buildings Institute.

Hendron, Robert, Farrar-Nagy, Sara, Anderson, Ren, Reeves, Paul, and Hancock, E., 2003. "Thermal Performance of Unvented Attics in Hot-Dry Climates: Results from Building America. Proceedings of the ISEC 2003: International Solar Energy Conference, March, pp. 73-80. New York: American Society of Mechanical Engineers.

Hinrichs, H.S., 1962. "Comparative Study of the Effectiveness of Ventilating Louvers," ASHRAE Transactions, Vol. 68, p. 297-309.

IECC, 2004. International Energy Conservation Code, "R806.4 Conditioned Attic Assemblies," 2004 ICC Final Action Agenda.

Imbert, Desmond, Drakes, Patrick, and Prevatt, David, 1994. "The Importance of Hurricane Risk Assessment In Housing and Improved Design and Building Practice Therein." In *Hurricanes of 1992*, Ronald A. Cook and Mehrdad Soltani, Editors. New York: American Society of Civil Engineers.

Joy, F.A., 1958. "Improving Attic Space Insulation Values," *ASHRAE Transactions*, Vol. 64, Atlanta: American Society of Heating Refrigerating, and Air Conditioning Engineers.

Keith, Edward L. 1994. "Performance of Plywood and OSB Sheathing During Hurricanes Andrew and Iniki." In *Hurricanes of 1992*, Ronald A. Cook and Mehrdad Soltani, Editors. New York: American Society of Civil Engineers.

Lstiburek, Joseph W., 2005. Rainwater Management Performance of Newly Constructed Residential Building Enclosures during August and September 2004, Prepared for Florida Homebuilder's Association, Building Science Corporation, January.

Parker, D., Sonne, J. and Sherwin, J., 2003. Flexible Roofing Facility: 2002 Summer Test Results, Prepared for: U.S. Department of Energy Building Technologies Program, July 2003

Parker, D.S., Sherwin, J.R. and Anello, M.T., 2001. FPC Residential Monitoring Project: New Technology Development Radiant Barrier Pilot Project, Florida Power Corporation, FSEC-CR-1231-01, Florida Solar Energy Center, Cocoa, FL.

Parker, D.S. Sonne, J.K., Sherwin, J.R. and Moyer, N., 2000. Comparative Evaluation of the Impact of Roofing Systems on Residential Cooling Energy Demand in Florida," FSEC-CR-1220-00, Florida Solar Energy Center, Cocoa, FL.

Parker, Danny S., and Sherwin, John R., 1998. "Comparative Summer Attic Thermal Performance of Six Roof Constructions." *ASHRAE Transactions*, TO-98-17-3, Atlanta: American Society of Heating Refrigeration and Air-Conditioning Engineers.

Parker, D.S. and Sherwin, J.R., 1998b. "Monitored Summer Peak Attic Air Temperatures in Florida Residences." *ASHRAE Transactions* 104 (2). Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

Parker, D.S., Fairey, P.W. and Gu, L., 1991. "A Stratified Air Model for Simulation of Attic Thermal Performance," Insulation Materials: Testing and Applications, Volume 2, ASTM STP 1116, R. S. Graves and D. C. Wysocki, Eds., American Society of Testing and Materials, Philadelphia.

Petrie, T.W., Stovall, T.K., Wilkes, K.E., and Desjarlais, A.O., 2004. Comparison of Cathedralized Attics to Conventional Attics: Where and When Do Cathedralized Attics Save Energy and Operating Costs? Oak Ridge: Oak Ridge National Laboratory.

Porter, W.A., "Vented vs. Unvented Attic Spaces in Florida's Hot Humid Climate," presentation to the Florida Building Commission, Agricultural and Biologicial Engineering, University of Florida, March 2005.

Quarles, Stephen L. 2002. " Conflicting Design Details in Wood Framed Construction," University of California, Richman Field Station, 9th Durability of Building Materials Conference, Brisbane, Australia. March 2002.

Roodvoets, D.L., 2001. "Practical Implications of the Elimination of Natural Attic Ventilation in Mixed Climates," Proceedings of the Thermal Performance of Exterior Envelopes of Buildings VIII, ASHRAE/DOE/BTECC, Clearwater, FL, December 2001.

Rose, William B. and TenWolde, Anton, 2002. "Venting of Attics and Cathedral Ceilings." *ASHRAE Journal*, October. Atlanta: American Society of Heating Refrigerating and Air-Conditioning Engineers.

Rose, William B., 1995. "Attic Construction with Sheathing-Applied Insulation." *ASHRAE Transactions*, 101 (2). Atlanta: American Society of Heating Refrigerating and Air-Conditioning Engineers.

Rose, W.B., 1992. "Measured Values of Temperature and Sheathing Moisture Content in Residential Attic Assemblies." Proceedings of the Thermal Performance of the Exterior Envelopes of Buildings V. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

Rose, W.B, 1992. "Measured Values of Temperature and Sheathing Moisture Content in Residential

Attic Assemblies," Proceedings of the Thermal Performance of the Exterior Envelopes of Buildings V Conference, ASHRAE, Clearwater, FL.

Rose, W. B., 2001, "Measured Summer Values of Sheathing and Shingle Temperatures for Residential Attics and Cathedral Ceilings," Performance of the Exterior Envelopes of Buildings VIII Conference, ASHRAE, Clearwater, FL.

Rudd, Armin, 2005. Personal Communication with author, Building Science Corporation, 10 January, 2005.

Rudd, Armin. 2004. Unvented-Cathedralized, Conditioned Attics: A Comprehensive Update, prepared with the Midwest Research Institute and the National Renewable Energy Laboratory, Building Science Corporation, June.

Rudd, Armin F., Lstiburek, Joseph W., and Ueno, Kohta, 2000. "Unvented-Cathedralized Attics: Where We've Been and Where We're Going." Proceedings of the 2000 ACEEE Summer Study on Energy Efficiency in Buildings, 23-28 August. Washington, D.C.: American Council for an Energy Efficient Economy.

Rudd, Armin F., and Lstiburek, Joseph W., 1998. "Vented and Sealed Attics in Hot Climates." *ASHRAE Transactions*, TO-98-20-3. Atlanta: American Society of Heating Refrigeration and Air-Conditioning Engineers.

Rudd, Armin F., Lstiburek, Joseph W., and Moyer, Neil A., 1996. "Measurement of Attic Temperatures and Cooling Energy Use in Vented and Sealed Attics in Las Vegas, Nevada." Proceedings: '96 Excellence in Building Conference. Minneapolis: Energy Efficient Building Association.

Shiao, M.L., D.A. Nester and L.A. Terrenzio, 2003. "On the Kinetics of Thermal Loads for Accelerated Aging," Roofing Research and Standards Development, 5th Volume ASTM STP 1451, W.J. Rossiter and T.J. Wallace eds., ASTM International, West Conshohocken, PA.

Shiao, M.L., 2005. "Personal communication with author," Certainteed Corporation, 15 February 2005.

Siegel, J., Walker, I. and Sherman, M., 2000. "Delivering Tons to the Register: Energy Efficient Design and Operation of Residential Cooling Systems, ACEEE 2000 Summer Study on Energy Efficiency in Buildings, Vol. 1, p. 294, American Council for an Energy Efficient Economy, Washington D.C.

TenWolde, Anton, and Rose, William B., 1999. "Issues Related to Venting of Attics and Cathedral Ceilings." *ASHRAE Transactions*, vol 105, pt 1. Atlanta: American Society of Heating Refrigerating and Air-Conditioning Engineers.

Terrenzio, L.A., et al., 1997. "Natural vs. Artificial aging: use of diffusion theory to model asphalt and fiberglass reinforced shingle performance," Proceedings of the Fourth International

Symposium on Roofing Technology, National Roofing Contractor's Association, Rosemont, IL

Testing Application Standard TAS 100 (A)-95, Test Procedure for Wind and Wind Driven Rain Resistance and/or Increased Windspeed Resistance of Soffit Ventilation Strip and Continuous or Intermittant Ventilation System Installed at the Ridge Area, Florida Building Code, High Velocity Hurricane Zones, Department of Community Affairs, Tallahassee, FL.

Turner, W.C. and Malloy, J.F., 1981. Thermal Insulation Handbook, McGraw-Hill Book Company, New York, NY.

Tye, R.P., Desjarlais, A.O., Yarbrough, D.W. and McElroy, D.L., 1980. An Experimental Study of Thermal Resistance Values of Low Density Mineral Fiber Building Insulation Batts Commercially Available in 1977, ORNL/TM-7266, Oak Ridge National Laboratory, Oak Ridge, TN.

Vickery, P., 2002. Roof Aerodynamics: Wind Pressure Loads, Boundary Layer Wind Tunnel Laboratory, Toronto, Canada, November, 2002.

Visscher, B., Kopp, G.A. and Vickery, P.J. 2004. Wind Loads on Houses: Destructive Model Testing of a Residential Gable Roofed House, ICLR Research Paper #37, Institute for Catastrophic Loss Reduction, Toronto, Canada.

Wilkes, K.E. 1991. Thermal Model of Attic Systems with Radiant Barrier Systems, ORNL/CON-262, Oak Ridge National Laboratories, Oak Ridge, TN.

Winady, J.E. and Beaumont, R., 1999. Roof Temperatures in Simulated Attics, FPL-RP-543, Forest Products Laboratory, Madison, WI.

Appendix A

technical bulletin

Asphalt Roofing Manufacturers Association

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Application of Asphalt Shingles Over Insulation or Insulated Decks

The Residential Roofing Committee of the Asphalt Roofing Manufacturers Association (ARMA) has established the following recommendations regarding the application of asphalt shingle products directly over insulation or insulated roof decks.

Shingle Application Directly Over Insulation:

1. Proper free-flow ventilation is impossible to achieve using this method. Heat build-up, which is typically a result of inadequate ventilation, may accelerate weathering and reduce the anticipated life of the asphalt shingles.
2. Asphalt shingles are likely to be damaged or punctured when nailed onto a non-rigid surface such as roofing insulation.
3. The nail-holding ability of the insulation is not adequate. Consequently, shingle damage and/or blow-off may occur if shingles are applied directly to insulation.
4. The fire ratings of various asphalt roofing products may be affected when applied directly over insulation. Individual manufacturers should be consulted to determine the effects on such ratings.

Shingle Application Directly Over Insulated Decks:

This type of application is not recommended unless an adequate free-flow ventilation space is created between the top of any insulation and the underside of a nailable deck. Proper ventilation must be provided to dissipate heat and humidity build-up under the roof top. (See ARMA Bulletin 209-RR-86 entitled *"Ventilation and Moisture Control for Residential Roofing."*)

In addition to affecting roof performance, direct applications of asphalt shingles over insulated decks without providing proper ventilation may void the shingle manufacturer's warranty. Individual manufacturers should be consulted to determine possible effects on their product warranties when such applications are utilized.

Some methods for creating free-flow air space for proper ventilation are shown in Figures A, B and C.

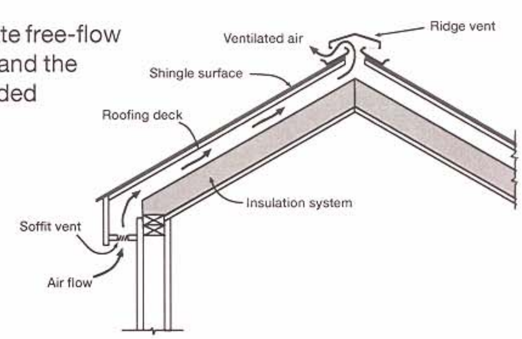

Figure A: Air flow through roof systems using soffit and ridge vents
(Most vent systems manufacturers recommend that ridge ventilation/ventilation ratios should be between 1/300 and 1/150 with a max. of 50% at the ridge.)

Note: These recommendations were prepared by and have the approval of the Asphalt Roofing Manufacturers Association for informational purposes only. They are not intended to revoke or change the requirements or specifications of the individual roofing material manufacturers or local, state and federal building officials that have jurisdiction in your area. Any question, or inquiry, as to the requirements, or specifications of a manufacturer, should be directed to the roofing manufacturer concerned.

(continued on back)

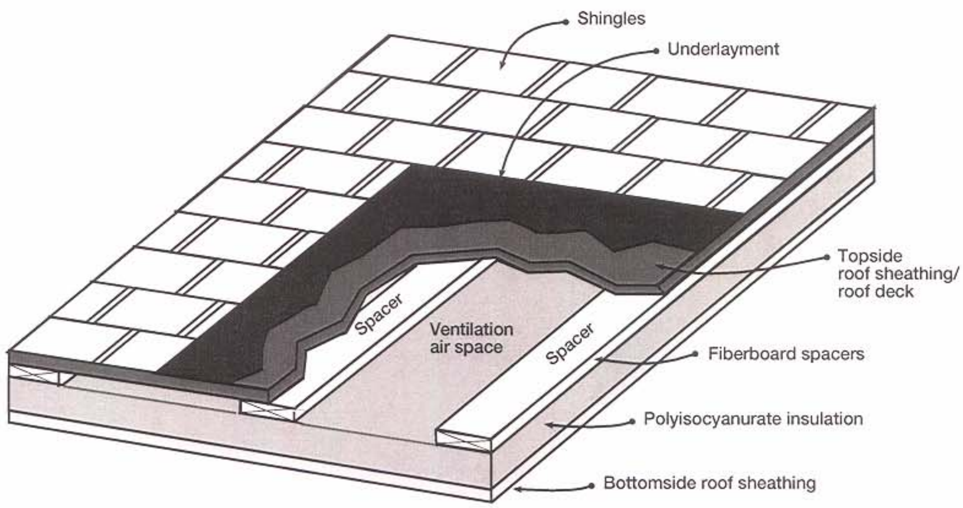

Figure B: Complete roofing assembly using a generic ventilated roof deck system
****(Factors influencing this measurement include: type of construction, roof pitch/run, temperature, humidity, etc. Consult the deck manufacturer, deck system designer and shingle manufacturer for specific requirements.)***

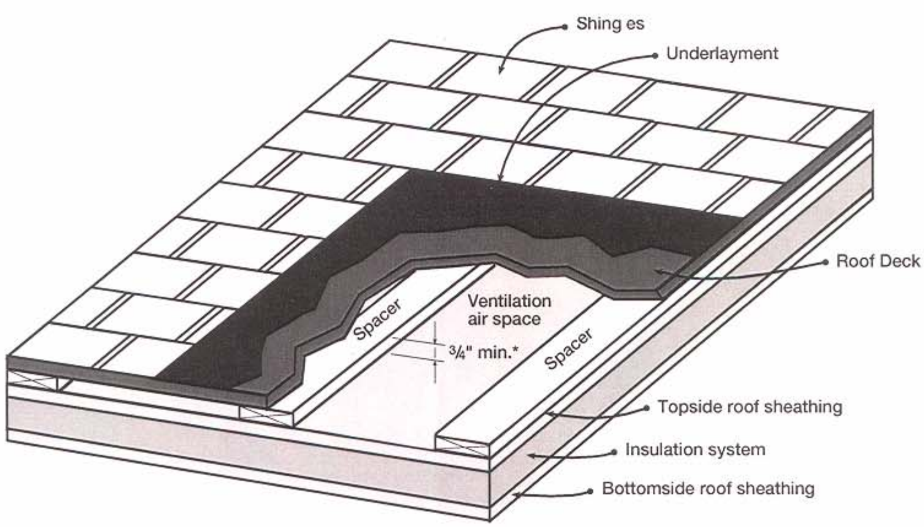

Figure C: Complete roofing assembly including spacers for ventilation
****(Factors influencing this measurement include: type of construction, roof pitch/run, temperature, humidity, etc.. Consult the deck manufacturer, deck system designer and shingle manufacturer for specific requirements.)***

Appendix B

FLORIDA SOLAR ENERGY CENTER

Spray foam insulation and water intrusion when applied to the underside of a roof deck assembly

Question: When a spray foam insulation has been applied to the underside of the roof deck and a roof leak develops, is the leak seen from below or is the water trapped between the decking and the insulation causing deck failure?

Answer: According to one manufacture, Icynene®, when posed the question. "*Does the Foam Entrap Moisture?*" Their response," Icynene Insulation is a breathing foam, and any moisture in the building's concrete or lumber can escape through the insulation as the building dries out, thus eliminating any risk of rot or mildew." (www.icynene.com)

Moisture intrusion may occur in the vapor or the liquid form. To consider the liquid form of intrusion, a sample roof section with a joint, without tar paper or shingles, was sprayed with Icynene to a depth of approximately 3 ½ inches. The assembly was placed such that a constant stream of water flowed over the upper surface of the assembly to observe the water paths.

After four hours of running water over the surface, the sample was torn apart to determine pathways. In the sheathing joint between the trusses:

1) no water was observed. In fact, the foam had effectively sealed the joint and protected the edges.
2) water entered the assembly and ran along the truss and lower surface of the sheathing.

Next a sample of Icynene was "hollowed out" like a soup bowl. Water was added and the sample with water was sealed in a plastic bag. It was placed in an air conditioned office. After two days, the water was still in the hollowed out area and no water appeared to pass thru the sample.




Appendix C

Attic Ventilation Experiments for Improved Thermal Performance and Storm Resistance in U.S. Housing: Proposed Building America Research Program

D. Parker
September 2004

Introduction

Additional attic ventilation is a commonly advocated method to reduce ceiling summertime heat gains in residential buildings. Increasing passive attic ventilation (wind and buoyancy driven ventilation) can be obtained by increasing the free inlet and outlet areas or by adding a ridge vent to take advantage of the stack effect. Although various means of augmenting passive ventilation may useful for new construction, this must be balanced from the emerging concerns of the impact of attic ventilation on attic and household moisture rates in very humid climates. Recent concerns associated with roof storm resistance against wind damage and water intrusion suggests the great importance of critical examination of roof/attic ventilation elements and their resistance to impact from storm events. Moreover, post mortem evaluation of roof systems after hurricanes show that where attic ventilation is used, effective ridge ventilation that retards rain intrusion is an important factor in reducing sheathing uplift damage and corresponding structural roof failure.[1]

Natural Ventilation of Attics

Although the adequacy of attic ventilation rates to reduce moisture accumulation in colder climates has received considerable attention (Harrje et al., 1979; Cleary, 1984; Spies, 1987), the actual impact on attic and whole house thermal performance is less well researched.[2] In one experiment where an attic was sealed, Wetherington (1979) found that attic ventilation made a moderate difference in attic air temperatures, but up approximately a 5% impact on house indoor humidity. Unfortunately, the study measurements were made using crude equipment and the experiment appears to have been influenced by attic cooling system duct leakage. Harrje et al. (1979) found that experimental change from soffit vs. ridge ventilation seemed to make little

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[1]One manufacturer with such a product is *Air Vent* (Air Vent Inc. 3000 West Commerce Street, Dallas, TX 75212) . These products feature an external baffle that is one of the keys to the ridge vent's outstanding performance. The baffle deflects wind up and over the vent, creating an area of negative pressure that causes lift and zone of negative pressure. This negative pressure works to pull air out of the attic. The baffle also deflects wind over the vent to help prevent wind_blown rain and snow from entering the attic.

[2]Determination of typical *in situ* ventilation rates in residential attics is spotty. Grot and Siu (1979) took test data on three houses in Houston, Texas which had soffit vents. Measured ventilation rates using sulfur hexafluoride (SF_6) tracer gas tests for the attics were 1.7 to 2.3 air changes per hour during the month of August, 1976. Cleary and Sonderegger (1984) made several measurements using SF_6 tracer gas to measure attic air change rates at various wind speeds in a house in Oroville, California. They found rates of 0.023 m^3/s per m/s wind speed in an attic with 3,000 cm^2 of soffit vents. Given the volume of the residential attic, this equates to an approximate air change rate of 4.6 air changes per hour (ACH) at a 7 m/s wind speed. Using similar SF_6 equipment Ford (1979) measured attic air change rates of 3 - 4 ACH under moderate wind conditions in Princeton, New Jersey. Dietz et al., measured a rate of 2.9 ACH in a long term tracer gas test on an attic in an Illinois house (1982). In a number of experiments using SF_6 tracer gas in two attics in Ocala, Florida, Ober (1990)measured average air change rates of 0.9 to 1.8 ACH in two attics in test periods ranging from 2 to 27 days. The various studies agree that wind speed is the primary driver of attic ventilation with thermal buoyancy of secondary importance.

difference on space cooling, but with the experimental periods too short, and with too varied weather conditions to reach valid conclusions. However, a carefully done simulation study of monitored Houston houses by Peavy (1979) estimated that ceiling heat flux would be reduced by up to 31% by effective ventilation vs. sealed operation. Parker and Sherwin (1998) found that 1:150 ventilation with an attic radiant barrier would reduce heat flux by 36% vs. 26% against a radiant barrier with only 1:300 ventilation. Unfortunately that study did not evaluate changes to the attic ventilation without radiant barriers.

An important study by Beal and Chandra (1995) found that a sealed attic versus one ventilated to standard levels (1:300 with soffit and ridge venting) yielded a 32% reduction to attic heat flux. However, the same study showed that the presence of a ridge vent only improved ceiling heat flux reduction by about 4%. Unfortunately, the measurement duration during this study were very short (subject to weather) and there were some questions about the actual ventilation areas in the testing and how they compared to HUD levels (1:300 and 1:150).

Although attic ventilation has been shown to reduce attic air temperatures and cooling loads the only examination of powered attic ventilators has shown the electricity consumption of the ventilator fans to be greater than the savings in air conditioning energy (Burch et al., 1979). Research on the impact of natural ventilation rates on the thermal performance of attics and homes has received scant attention.

Code Requirements

According to most building codes, residential homes need 1 square foot of ventilation or net free area for every 300 square feet of attic floor space (FHA, 2003). Net free area is the total unobstructed area through which air can enter or exhaust a non_powered ventilation system.

- For new home construction that includes a vapor barrier, the minimum is 1 square foot of ventilation or net free area for every 300 square feet of attic floor space.

- If vents are split between ridge vents and intake vents, the minimum requirement is also 1 square foot of ventilation or net free area for every 300 square feet of attic floor space.

- If no vapor retarder is used and/or proper distribution of under eave and ridge vents cannot be achieved (50% of ventilation as ridge vents), one square foot of net free vent area should be provided for each 150 square feet of attic floor or area to be vented.

- For a balanced system, ventilation should be equal at the undereave and ridge.

Codes vary somewhat in interpretation from one geographic region to the next. Some jurisdictions allow new sealed attic construction, while others do not. Although the 50% distribution rule within the code requires both soffit and ridge vents, it seems very unlikely that 1:150 is ever enforced based on calculation alone. Often, the code approval is based on the least common denominator: “building has perforated soffit vents and ridge vents= pass.”

Adverse Impacts of Attic Ventilation

While there is consensus that attic ventilation can improve summer thermal performance, emerging evidence suggests problems with ventilated attics in humid climates. Recently, the issue of attic ventilation has become a contentious issue, in part due to the lack of scientific basis for the 1:300 free ventilation rate (Rose, 1995). Also measured and simulated influences of ventilation on humidity of attic materials suggest that attic ventilation may lead to problems in hot and humid climates (Burch et al., 1996; TenoWold and Rose, 1999). The major problem is that passively ventilated attic bring in large amounts of moisture laden air into the attics during evening hours when relative humidity is often high. This can lead to sweating air conditioning ducts (and air handlers) with associated insulation and even ceiling damage.

Forced Ventilation**:**

Increasing attic ventilation rates in existing residential buildings is often accomplished by adding forced ventilation using attic temperature activated attic fans. However, even those who are in favor of increased attic ventilation have often warned that the energy consumption associated with the attic fan motor is likely greater than any realized energy savings from its use (Wolfert and Hinrichs, 1974). Also, an early detailed study showed that while forced attic ventilation did reduce cooling energy use, the reduction was quite small and outweighed by the energy consumption of the fan itself (Dutt and Harrje, 1979). Another study in two instrumented side-by-side homes in Texas came to similar conclusions (Burch and Treado, 1979). Forced ventilation was found to reduce ceiling heat gain by 1.1 $Btu/hr/ft^2$ (328 W) over soffit venting and gains to the attic duct system by 94 W.[3] At a normal air conditioning COP of 3, the overall reduction in cooling energy use could be expected to be approximately 140 W against the measured consumption of 284 W by the ventilation fan. Measured reduction to the maximum cooling load was only 6% for R-11 ceiling insulation. Thus, the powered ventilation does not typically result in a net energy savings unless the attic is uninsulated. Under this scenario, other means of controlling attic heat gain are preferable and more cost effective than forced ventilation. Other analysis, tends to verify this conclusion. Detailed simulations suggest that the heat transfer in an attic to a residential building interior in mid-summer is dominated by radiative gains from the hot roof decking directly to the insulation surface (Parker et al., 1991; Wilkes, 1991). This mode of heat transfer is more effectively limited by 1) increased attic insulation, 2) a truss-mounted radiant barrier or 3) a white reflective roof surface that limits solar gain to the attic structure.

Most attic ventilators often draw 250 - 300 Watts of electric power when in operation (they are typically triggered on when the attic air temperature reaches 105EF or more). For a single ventilator (often two or more are used), this level of electrical use (approximately 10% of the peak air conditioner power draw) is greater than the savings in space cooling energy (6% as shown by Burch et al., 1979).

Poor performance and unattractive economics serves as the main limitation to more common use of forced attic ventilation. Other than questionable performance, there are other potential problems with powered attic ventilation. Tooley and Davis (1994) have found that powered attic ventilation can effectively cause negative pressures in combustion appliance zones-- a potentially dangerous situation--

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3 Interestingly, Burch and Treado (1979) found ridge or turbine ventilation to be nearly as effective as forced ventilation in reducing the overall attic temperature profile, producing a an average reduction in the ceiling heat flux of about 19%. Still, however, the authors concluded that this represented no more than a 3% reduction in the overall building cooling load under maximum conditions.

as well as drawing conditioned air from the building interior through leakage in the ceiling/attic interface. This could serve to increase building cooling latent loads and offset any potential energy savings associated with powered attic ventilation.

Another solution is to use ventilator fans with no parasitic electricity consumption beyond what is generated by the unit. Typically, this involves using photovoltaics to power ventilation fans. Such solar powered attic ventilators are now commonly available. One intrinsic advantage of a photovoltaic powered attic ventilation scheme is that the attic is well ventilated only during daytime hours only when considerable insolation is present. Coincidently, these also tend to be periods when the ambient relative humidity is low. This method will not effectively ventilate the attic during humid nighttime periods nor during rainy periods when outdoor moisture is high. Also, so attic ventilation can be switched off in the event of adverse weather. One other advantage of the PV ventilators over AC powered units is noise. Although not quantified within a previous study, we did note that PV vent fans are very quiet in operation compared with the very noticeable fan noise generated by conventional units.

A case study was performed on two photovoltaic attic ventilator fans retrofitted into an occupied 1500 square foot family home in Central Florida (Parker & Sherwin, 2000). Comparing periods with similar weather conditions, the test revealed that the PV vent fans have the potential to reduce measured peak summer attic air temperatures by over 20EF. However, the impact over the cooling season is fairly modest with well insulated attics. Measured space cooling reduction was approximately 6%-- worth about 460 kWh annually at the test home. Still, this strategy may have other benefits relative to attic humidity control and the ability to halt ventilation by simple switching during extreme weather events. Although PV ventilators claim to be resistant to wind-borne rain intrusion, independent testing would be desireable.

<u>Roof/Attic Ventilation Interaction with Potential for Hurricane Damage</u>

Heavy rain in a hurricane adds to the danger of the storm as evaluated in detailed post mortem assessments conducted by HUD (1993) after Hurricanes Andrew and Iniki. Hurricane Andrew, a fairly dry storm because of its high forward speed, still dumped 10 inches of rain on south Florida and left many buildings extensively water-damaged. Water seeping into gaps between the roof sheathing saturated insulation and ceiling drywall and caused some buildings to collapse (Wolfe et al., 1994). Rain quickly saturated the insulation and the ceiling. The loss of ceiling strength due to water saturation, and the increased weight of the wet insulation, caused widespread collapse of ceilings. Nearly 65% of homes exposed to Andrew, and 40% of homes exposed to Hurricane Iniki, had water damage.

When houses were exposed to hurricane forces, roofs were most susceptible to damage, followed by walls and openings, and then foundations. The data show clearly that roofs are damaged more often than any other building component (Manning and Nichols, 1991). Roof coverings which were not adequately attached, and corner and eave and ridge regions of roofs were frequently damaged. Smith and McDonald (1991) note that in the Charleston area probably more than 75% of all roofs had at least minimal damage. Once roofs were breached, house interiors were exposed to further damage from water. Roof failures were also the most frequently observed structural failures from Andrew. Cook (1991) estimates that over 80% of losses were related to roof failures and associated water damage. In Dade County, Florida, the most common building failure observed was loss of roof cladding (shingles, tiles, etc.). Ninety percent of all homes in Dade County had some degree of roof damage (Doehring et al., 1994).

Water penetration was a major problem whenever roofing material was removed by wind action. For steep roof systems, many roofing failures occurred at the ridge or gable ends where wind_induced forces were the highest. Gable ends were consistently found to increase the chances of roof failure in a number of forensic tests after hurricanes. On the other hand, Cook et al. (1994) recommended that adding ridge ventilators could reduce uplift of roof sheathing from pressures exhibited from soffit-only ventilation. The same conclusion was reached in an evaluation of roof sheathing failures in the wake of Hurricane Andrew (Miller, 1993). Thus, ridge vents look important for hurricane resistance, but must effectively reduce wind-driven rain intrusion to prevent damage. Some newer models have external weather baffles along with internal weather filters. UL testing of these ridge vents supposedly evaluates their resistance to wind driven rain up to speeds of 110 mph, but we know of no other evaluation of this roofing component in spite of some experience with moisture damage as found by building inspectors.

Research Plan

Due to the fundamental influence of attic ventilation on attic thermal performance, and the poor availability of long-term comparative data, we recommend that priority research for the summer of 2005 use FSEC's Flexible Roof Facility (FRF) to examine attic ventilation influences. The FRF would be set up in the following configuration to establish relative performance. All cells would have black shingles save for Test 6 six with the white metal roof which has served for years as the best performing roofing system. All test cells would have R-30 insulation installed on the attic floor with the ventilation areas carefully verified by blower door pressurization.

Cell No.	Description of Experiment Conditions in Test Cell	Justification within experiment
6	White metal roof, 1:300 ventilation	Best performing roofing system.
5	Reference, 1:300 ventilation area	Standard requirement for building codes
4	Black shingles, 1:150 vent area	Added attic ventilation area per codes
3	Black shingles, Sealed	New ASHRAE recommendation to reduce attic humidity
2	Black shingles, 1:150, soffit vs. ridge	Evaluation impact of soffit vs. ridge venting
1	Black shingles, open soffit with PV vents	Evaluate impact of PV ventilators soffit, but no ridge venting

Test cell #2 would alternately have the ridge vents opened and closed midway through the summer season to examine influences on performance. Relative humidity sensors would be used to evaluate how the different attic ventilation strategies influence attic moisture conditions.

In addition, moisture sensors would be placed in the areas surrounding the ridge vents to see if wind blown moisture is introduced to the attics during weather events. At the end of the monitoring, another experiment would use an aerated spray to examine potential rain intrusion problems.

Monitoring would continue in the given configuration for an entire year to examine both cooling and heating related performance. Collected data will be used to refine attic models used for building simulations used both within DOE-2.1e and Energy Plus. Results would the attic ventilation assessment would be widely published and shared within the building research community.

References

D. Beal and S. Chandra, 1995. “The Measured Performance of Tile Roof Systems and Attic Ventilation Strategies in Hot and Humid Climates,” Thermal Performance of the Exterior Envelopes of Buildings VI, ASHRAE/DOE/BTECC, December, 1995.

Burch, D.M. and Treado, S.J., 1979. "Ventilating Residences and their Attics for Energy Conservation--An Experimental Study," in Summer Attic and Whole House Ventilation, National Bureau of Standards Special Publication 548, Washington D.C.

P. Cleary and R. Sonderegger,1984."A Method to Predict the Hour by Hour Humidity Ratio of Attic Air," Lawrence Berkeley Laboratory, LBL-17591, Berkeley, CA.

R. A. Cook, 1991. "Lessons Learned by a Roof Consultant." Hurricane Hugo One Year Later, Benjamin A. Sill and Peter R. Sparks, Eds. NY: American Society of Civil Engineers.

R.A. Cook; Mehrdad Soltani; and Timothy A.Reinhold. 1994. "Lessons Learned from the Hurricanes of 1992." In Hurricanes of 1992, Ronald A. Cook and Mehrdad Soltani, Eds. New York: American Society of Civil Engineers.

Dietz, R.N., Goodrich, R.W., Cote, E.A. and Wieser, R.F., "Detailed Description and Performance of a Passive Perfluorocarbon Tracer System for Building Ventilation and Air Exchange Measurements," Measured Air Leakage in Buildings, ASTM STP 904, American Society for Testing and Materials, Philadelphia, PA, 1986.

F. Doehring, I. W.Duedall; and J. M. Williams. 1994. Florida Hurricanes and Tropical Storms 1871_1993: An Historical Survey. Gainesville: Division of Marine and Environmental Systems, Florida Institute of Technology.

G.S. Dutt and D.T. Harrje, 1979. "Forced Ventilation for Cooling Attics in Summer," in Summer Attic and Whole House Ventilation, National Bureau of Standards Special Publication 548, Washington D.C.

J.K. Ford, 1982. Heat Flow and Moisture Dynamics in a Residential Attic, Master's of Science Thesis, Center for Energy and Environmental Studies, CEES Report - 148, Princeton University, Princeton, N.J.

R.A. Grot and C.I. Shiu, 1979."Effectiveness of Powered Attic Ventilation on Ceiling Heat Transfer and Cooling Load in Two Townhouses," in Summer Attic and Whole House Ventilation, NBS Special Publication 548, Washington D.C, 1979.

Harrje, D.T., Gibson, R.G., Jacobson, D.I., Dutt, G.S. and Hans, G., "Field Measurements of Seasonal Wood Moisture Variations in Residential Attics," Report No. 173, Center for Energy and Environmental Studies, Princeton, N.J., 1984.

Federal Housing Administration (FHA), 2003, “Minimum Property Standards: International Residential Energy Code,” Section R806, Washington D.C.

U.S. Department of Housing and Urban Development (HUD), 1993. Assessment of Damage to Single_Family Homes Caused by Hurricanes Andrew and Iniki. Office of Policy Development and Research, Washington, D.C.

B.R. Manning and G. G. Nichols. 1991. "Hugo Lessons Learned." Hurricane Hugo One Year Later, Benjamin A. Sill and Peter R. Sparks, Eds. NY: American Society of Civil Engineers.

Charles Miller, 1993 "Hurricane Warnings: Sifting Through the Wreckage of Hurricane Andrew to Learn Why Some Houses Survived and Some Didn't" Fine Homebuilding, #76, Tauton Press.

D.G. Ober,1990. Attic Insulation Performance: Full Scale Tests of Conventional Insulation and Radiant Barriers, Mineral Insulation Manufacturer's Association, Final Report, Denver, CO.

Parker, D.S., Fairey, P.F., Gu, L., 1991. "A Stratified Air Model for Simulation of Attic Thermal Performance," Insulation Materials: Testing and Applications, ASTM STP 1116, American Society of Testing and Materials, Philadelphia, PA.

D. Parker and J. Sherwin, 1998. "Comparative Summer Attic Thermal Performance of Six Roof Constructions,"ASHRAE Transactions, Vol. 108, Pt. 2 , FSEC_PF_338_98, Florida Solar Energy Center, Cocoa, FL.

D. Parker and J. Sherwin, 2000. "Performance Assessment of Photovoltaic Attic Fans," Presented at: The 12th Symposium on Improving Building Systems in Hot and Humid Climates, May 15_17, 2000, San Antonio, TX

B. A. Peavy, 1979, "A Model for Predicting the Thermal Performance of Ventilated Attics," in Summer Attic and Whole House Ventilation, National Bureau of Standards Special Publication 548, Washington D.C.

W.B. Rose, "The History of Attic Ventilation Regulation and Research," Thermal Performance of the Exterior Envelopes of Buildings VI, ASHRAE/DOE/BTECC, p. 125, December, 1995.

T.L. Smith and J. R. McDonald. 1991. "Roof Wind Damage Mitigation: Lessons from Hugo." In Hurricane Hugo One Year Later, Benjamin A. Sill and Peter R. Sparks, Editors. New York: American Society of Civil Engineers.

Spies, H., "Attic Ventilation: How much you need and why," Progressive Builder, August, 1987, 1987, p. 21-23.

A. TenoWolde and W.B. Rose, "Issues Related to Venting of Attics and Cathedral Ceilings," ASHRAE Transactions, CH-99-11-4, p. 851-857, Summer, 1999, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA.

Tooley, J.J. and Davis, B.E., 1994. "Powered Attic Ventilators, Another Building Science Nightmare and Treasure Trove," Proceedings of the 1994 Summer Study on Energy Efficiency in Buildings, Vol. 5, American Council for an Energy Efficient Economy, Washington D.C.

T.I. Wetherington, Jr., 1979. "Measurement of Attic Temperatures in Florida," in Summer Attic and Whole House Ventilation, National Bureau of Standards Special Publication 548, Washington D.C.

Wilkes, K.E., 1991. Thermal Model of Attic Systems with Radiant Barriers, ORNL/CON-262, Oak Ridge National Laboratories, Oak Ridge, TN.

Wolfe, Ronald W.; Ramon M. Riba; and Mike Triche. 1994. "Wind Resistance of Conventional Light_Frame Buildings." Hurricanes of 1992, Ronald A. Cook and Mehrdad Soltani, Eds. NY: American Society of Civil Engineers.

Wolfert, C.K. and Hinrichs, H.S., 1974. Fundamentals of Residential Attic Ventilation, H.C. Products Company, Princeville, IL.

Appendix D

Evaluation of Hurricane Resistant Roof and Attic Constructions
An Evaluation Using Numerical Methods Simulating Hurricane Conditions

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There are two types of attic constructions: vented attic and sealed attic. Many studies have been done to provide information on advantages and disadvantages for both attic types from a point view of energy and moisture under normal weather conditions. Also, investigations in the wake of several hurricanes, done by the U.S. Department of Housing and Urban Development has show that for steep roof systems, many roofing failures occurred at the ridge or gable ends where wind-induced forces were the highest. For low-slope roof systems, damage occurred primarily at roof corners (Chiu et al., 1994). Gable-ended construction also appears particularly problematic. Keith (1994) observed that the most common type of structural damage from Hurricane Andrew in Florida was loss of gable-end walls.

Also, within this same empirical data, ventilated attics showed considerable sheathing uplift during hurricane events—potentially leading to roof failure—particularly when ridge vents are not provided (soffit venting only) (Cook, 1994). FEMA (1993). However, there is no study to compare performance for various attic types under hurricane wind conditions. When wind speed reaches the hurricane level, the vented attic has not only much higher ventilation rate, but also much higher moisture intrusion due to horizontal rain, in addition to high pressure on the roof surface. In contrast to the vented attic, the sealed attic only need to endure wind pressure on the rood surface without moisture intrusion.

The proposed work will investigate attic performance under hurricane conditions. A computational fluid dynamics (CFD) software, FLUENT, will be used as a tool to perform simulations. The possible parameters will consist of roof vent size, location, and soffit size for the vented attic, and attic configuration for both attic types, such as hip roof vs. gable roof. A three dimensional representation will be used based on data showing its importance for modeling of wind uplift. For instance, uplift forces are greatest at the corners of the roof. The flow mechanism responsible for this phenomenon is called roof vortex. Roof vortexes can generate extreme suction peaks along each of the two leading edges at each roof corner (Tieleman, 1994). These local suction forces can be 2,5 times those on other parts of the roof (Imbert et al., 1994).

Simulation results include attic pressure distribution in both attic types and airflow pattern in the vented attic. In addition to examination of the pressure distribution and air flow pattern, moisture study will be performed to examine moisture distribution in the vented attic caused by high moisture intrusion. Analysis of simulation results will provide a design guidance of attic constructions for both attic types in order to resist wind and rain with the hurricane level. This would include:

- Relative wind resistance of sealed attic vs. ventilated attic construction.
- Influence of soffit venting only vs. soffit and ridge venting for vented attics
- Impact of gable end venting vs. ridge venting
- Interaction of roofing material type on estimate mean wind speed at failure within the above configurations.

Where possible, the simulation results would be bolstered by available empirical data.

Proposed time: 12 months
Estimated budget: $180,000

References:

Chiu, Gregory L.F.; Dale C Perry; and Arthur N.L.Chiu. 1994. "Structural Performance in Hurricane Iniki." In *Proceedings of Seventh United States National Wind Engineering Conference*, Volume I, Gary C. Hart, Editor. Washington, D.C.: National Science Foundation.

Cook, Ronald A. 1994. "Overview of Hurricane Andrew in South Florida." In *Hurricanes of 1992*, Ronald A. Cook and Mehrdad Soltani, Editors. New York: American Society of Civil Engineers.

Imbert, Desmond; Patrick Drakes; and David Prevatt. 1994. "The Importance of Hurricane Risk Assessment In Housing and Improved Design and Building Practice Therein." In *Hurricanes of 1992*, Ronald A. Cook and Mehrdad Soltani, Editors. New York: American Society of Civil Engineers.

Keith, Edward L. 1994. "Performance of Plywood and OSB Sheathing During Hurricanes Andrew and Iniki." In *Hurricanes of 1992*, Ronald A. Cook and Mehrdad Soltani, Editors. New York: American Society of Civil Engineers.

Tieleman, Henry W. 1994. "Wind Loads on Roofs of Low Rise Structures: Buffeting or Interaction." In *Hurricanes of 1992*, Ronald A. Cook and Mehrdad Soltani, Editors. New York: American Society of Civil Engineers.

U.S. Department of Housing and Urban Development (HUD), Office of Policy Development and Research. 1993. *Assessment of Damage to Single-Family Homes Caused by Hurricanes Andrew and Iniki*. Washington, D.C.: HUD.