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Monitored Summer Peak Attic Air Temperatures in Florida Residences

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Abstract

Florida Solar Energy Center (FSEC) has analyzed measured summer attic air temperature data taken for some 21 houses (three with two different roof configurations) over the last several years. The analysis is in support of the calculation within ASHRAE Special Project 152P which will be used to estimate duct system conductance gains which are exposed to the attic space. Knowledge of prevailing attic thermal conditions are critical to the duct heat transfer calculations for estimation of impacts on residential cooling system sizing.

The field data was from a variety of residential monitoring projects which were classified according to intrinsic differences in roofing configurations and characteristics. The sites were occupied homes spread around the state of Florida. There were a variety of different roofing construction types, roof colors and ventilation configurations. Data at each site were obtained from June 1st - September 30th according to the ASHRAE definition of summer. The attic air temperature and ambient air temperature were used for the data analysis. The attic air temperature was measured with a shielded type-T thermocouple at mid- attic height, halfway between the decking and insulation surface.

The ambient air temperature was obtained at each site by thermocouple located inside a shielded exterior enclosure at a 3-4m (10-12 foot) height. The summer 15-minute data from each site were sorted by the average ambient air temperature into the top 2.5% of the observations of the highest temperature. Within this limited group of observations, the average outside air temperature, attic air temperature and the coincident difference was reported.

Introduction

Characterization of attic thermal performance in hot climates is vital to estimation of ceiling heat transfer to the interior space. However, equally important in air conditioned buildings is how prevailing attic thermal conditions impact duct heat transfer. This has been detailed in simulation analysis (Parker et al., 1991, 1993 and Gu et al., 1996), laboratory testing (Petrie and Christian, 1996) and field monitoring (Jump et al., 1996; Hageman and Modera, 1996).

FSEC has performed numerous experiments in test buildings over the last decade on the potential of a variety of methods to reduce attic air temperatures in Florida residences. This includes radiant barrier systems (Fairey et al., 1988), white reflective roofs (Parker et al., 1995), enhanced attic ventilation and roof tiles (Beal and Chandra, 1995) and sealed attics with insulation in the roof system (Rudd, et al., 1996). Attic air temperatures vary considerably depending on roofing type, color and ventilation. A good example of the importance of roof reflectance is shown in Figure 1 which plots the measured attic air temperature in a monitored residential site in Florida over the summer months in which the roof was made white on July 6th (Parker and Barkaszi, 1997).

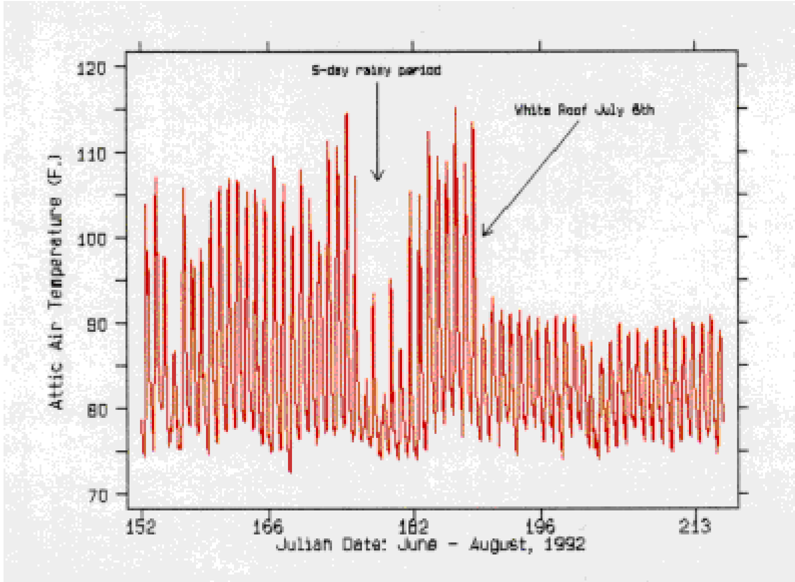

Figure 1. Measured 15-minute attic air temperatures in a residence before and after roof was whitened in the summer of 1992. After roof was whitened attic air temperature was often lower than ambient due to heat transfer to the AC duct system.

The potential importance of attic ventilation has been investigated by an early series of NBS studies (Reppert ed., 1979).

The field data presented are from a variety of projects associated with these parameters and are classified according to intrinsic differences. Each building is classified by a three letter/number code; the sites are spread around the state of Florida.(1) There are a variety of different roofing construction types, colors and ventilation configurations represented. Truss-mounted radiant barriers were present in two attic constructions.

Methodology

Summer data at each site was obtained from June 1st - September 30th according to the ASHRAE definition of summer. The attic air temperature and ambient air temperature were used for the data analysis. The attic air temperature was taken at mid- attic, halfway between the decking and insulation surface. The attic air temperature was taken with a shielded type-T thermocouple. The ambient air temperature was obtained at each site by a thermocouple located inside a shielded exterior enclosure at a 3-4m (10-12 ft) height adjacent to the building (See Figure 2).

Figure 2. Installation of a shielded thermocouple for measurement of site ambient air temperature. Houses in the background are those of a Habitat of Humanity development of which ten houses (see Table 1) have been metered for two years. House has light gray, blue and dark gray shingles.

The 15-minute summer data from each site comprised 11,712 observations. These were sorted by the average ambient air temperature into the top 2.5% of the observations (~293) of the highest temperature corresponding to the ASHRAE design condition. Within this limited group of observations, the average outside air temperature, attic air temperature and the coincident difference are reported. Figure 3 shows an example of the measured attic air temperature at one of the sites (HO2) over an entire summer.

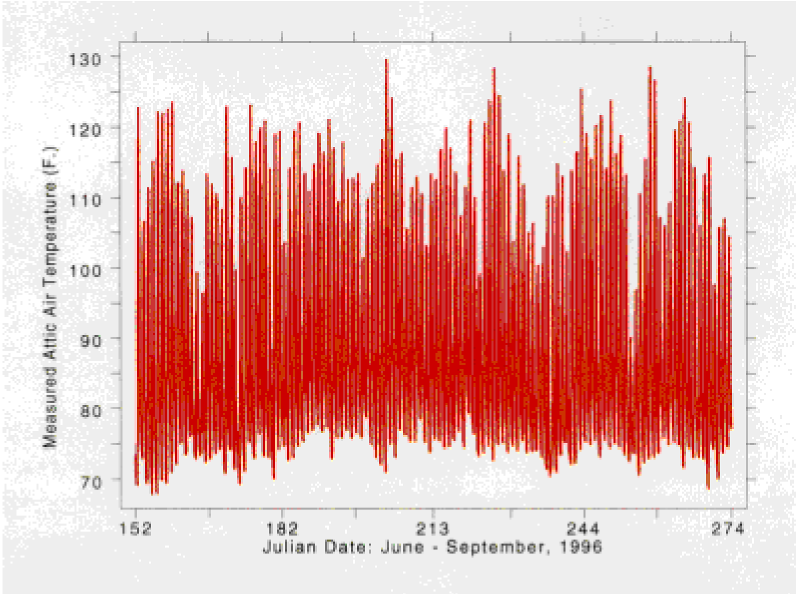

Figure 3. Measured attic air temperature at site HO2 over the entire summer of 1996. House has a dark gray asphalt shingle roof and is located in Homestead, Florida.

Results

The tabular results from the above analysis are given below in Tables 1 -5 and in Figure 4 as classified by roof type, color and ventilation.

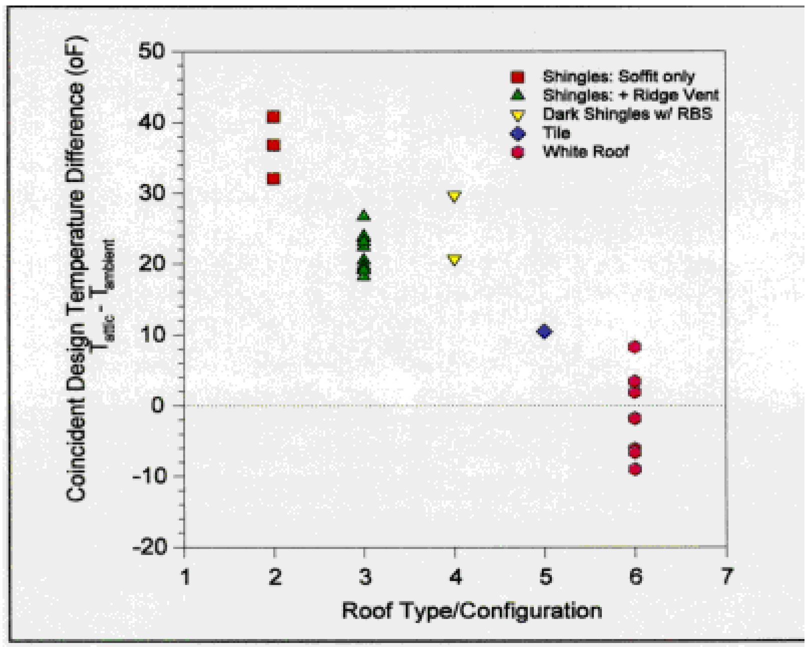

Figure 4. Coincident attic to ambient air temperature difference at ASHRAE summer design condition.

It is worth noting that light gray or "white" asphalt shingles have a measured solar absorptance of approximately 75% as opposed to true reflective roofing systems which have absorptances less than 30% (Parker et al., 1993B). Dark gray shingles have a solar absorptance of about 90%.

Table 1
Shingle Roofs with Soffit and Ridge Vents

Designation	Tamb	Tattic	dT	Location	Year	Comments
H01	91.5°	110.8°	19.3°	Homestead	1996	Lt. Gray shingle

H02	91.1°	111.6°	20.5°	Homestead	1996	Lt. Gray shingle
H03	90.6°	108.8°	18.2°	Homestead	1996	Lt. Gray shingle
H04	91.1°	110.8°	19.7°	Homestead	1996	Lt. Gray shingle
H05	91.0°	117.7°	26.7°	Homestead	1996	Dark Gray shingle
H06	90.8°	113.1°	22.4°	Homestead	1996	Med. Blue shingle
H07	91.7°	110.8°	19.1°	Homestead	1996	Lt. Gray shingle
H08	90.0°	114.9°	23.1°	Homestead	1996	Dark Gray shingle
H09	91.5°	115.1°	23.7°	Homestead	1996	Med. Blue shingle
H10	90.9°	114.8°	23.9°	Homestead	1996	Dark Gray shingle
Avg			21.7°			

Table 2
Shingle Roofs with Soffit Venting Only

Designation	Tamb	Tattic	dT	Location	Year	Comments
ACC	95.0°	127.2°	32.1°	Belle Glade	1995	Med. Gray shingle
CBS	95.0°	127.1°	32.1°	Belle Glade	1995	Lt. Brown shingle
CR1	97.1°	133.9°	36.8°	Hollywood	1995	Black shingles
RC3	91.4°	132.3°	40.8°	Nobleton	1995	Dk. Brown shingle, no ducts
Avg			35.5°			

Table 3
Shingle Roofs with Radiant Barrier and Various Venting

Designation	Tamb	Tattic	dT	Location	Year	Comments
CR1	97.2°	117.9°	20.7°	Hollywood	1996	Black, Soffit & Ridge vent
WD1	95.2°	125.0°	29.7°	Cocoa	1996	Dk. Brown, Soffit vent only

Table 4
Tile Roof, Direct Nailed, Standard Venting

Designation	Tamb	Tattic	dT	Location	Year	Comments
RC5	96.6°	107.2°	10.5°	Merritt Island	1993	Gray tile

Table 5
White Roofs and Various Venting

Designation	Tamb	Tattic	dT	Location	Year	Comments
DSP	94.9°	88.6°	-6.1°	Cocoa Beach	1993	White shingle ridge/soffit vents
RC5				Merritt Island	1995	

	94.4°	91.6°	-2.9°			White tile (2^{nd} yr.)
RC3	91.7°	93.6°	1.9°	Nobleton	1994	White (2^{nd} yr.)
RC9	93.1°	84.0°	-9.0°	Cocoa	1995	White gravel (2^{nd} yr.)
PT2	91.7°	95.2°	3.4°	Palm Bay	1995	White shingle (2^{nd} yr.)
RC4	93.4°	87.8°	-6.6°	Miami	1994	White gravel (2^{nd} yr.)
LS1	95.1°	103.4°	8.3°	Merritt Island	1995	White shingle (2^{nd} yr.)
Average			-1.5			

Discussion

The data set highlights prominent influences on attic thermal performance. The first set of data are from ten 1,100 square foot ($100m^2$) homes of virtually identical construction in Homestead, Florida. Each has both soffit and ridge venting. Only the shingle color varies, an important influence as suggested by the temperature data shown both in tabular form and illustrated in Figure 5.

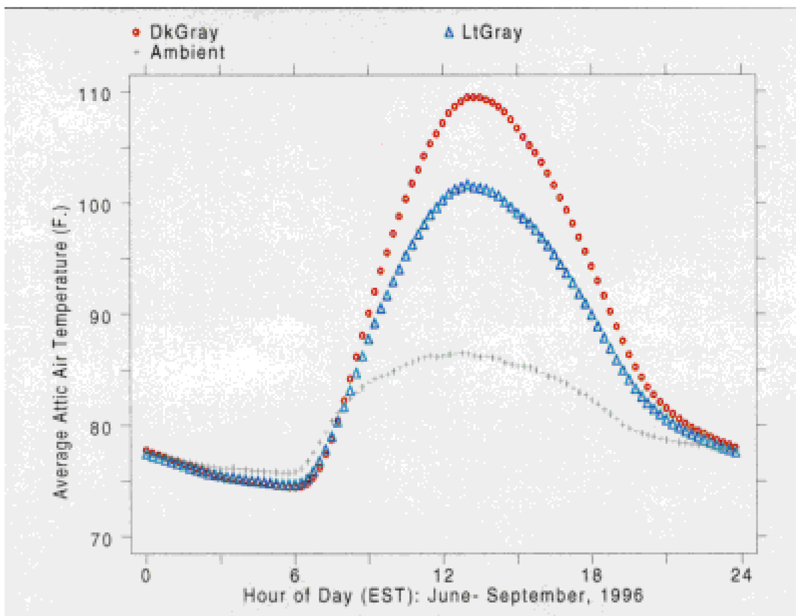

Figure 5. Influence of asphalt shingle color on measured average attic air temperature at two adjacent Homestead, Florida sites (HO2 and HO5) during the summer of 1996.

Data from the second group of four homes suggests that soffit venting only can result in substantially higher temperatures than with soffit and ridge venting. This is likely a result of increased ventilation. Note that there are two data sets for location CR1. The first is in its initial condition with a black roof and very little ventilation; the second year is with an attic radiant barrier and soffit and ridge venting. The attic to ambient dT is reduced by 16°F (8.9°C). There are also two years with site RC5, one with gray tile and the other with white tile - both configurations showing better performance than shingle roofs.

The data from the homes with white roofs show some variance, but generally indicate much lower coincident attic air temperatures during summer peak conditions. Site RC3 has data from a period with a dark shingle roof and a white roof with dramatic differences. Often with a white roof the attic to ambient temperature difference is negative - seemingly counterintuitive. There are several reasons:

- Where duct systems are present in attics (all houses, but RC3 above) the heat transfer to the duct system tends to pull the attic air temperature down lower than would occur without this influence. This impact is illustrated in Figure 6 which shows how measured attic air temperatures dropped at site WD1 when the air conditioner was turned on at 1 PM.

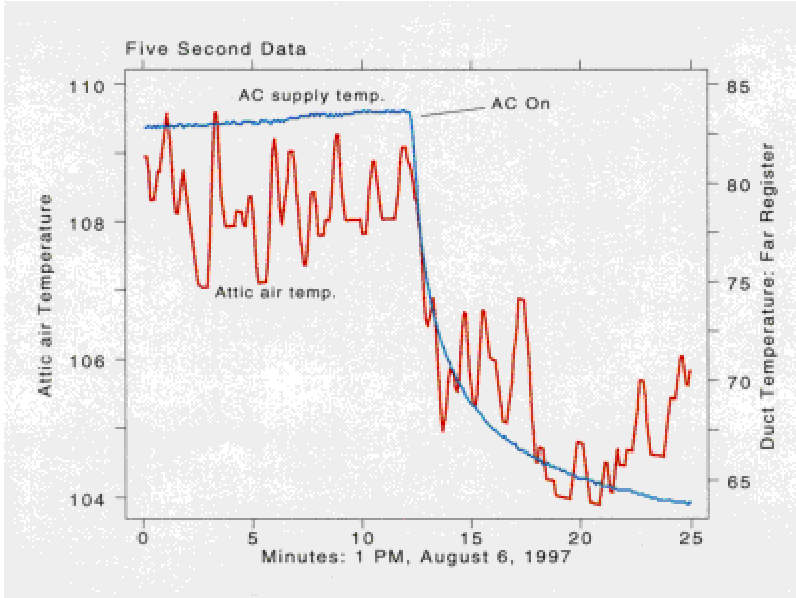

Figure 6. Influence of duct system heat gain on measured attic air temperature site WD1, August 6, 1997. Short term fluctuations of attic air temperature appear correlated with wind conditions.

- With a white roof, the solar gain is minimized, so the impact becomes much more apparent. Also, supply leaks from the duct system may further exaggerate this influence as seen by thermography at several sites. Also, heat transfer from the attic to the air conditioned zone tends to reduce attic air temperatures, particularly when low temperatures are maintained (RC9).
- The attic cools off well below ambient temperatures during evening hours (emitting to night sky) and does not rise to the same level as the ambient air temperature since much of the morning hours are spent evaporating moisture (dew) from the roof surface.
- The attic air temperature peak may be out of phase with the peak ambient air temperature -- particularly for white tile and gravel roof types which have greater thermal capacitance.

Conclusions

Although the 21-house data set is not large enough to comprise a statistical sample, it does suggest some important influences on summer attic design temperatures in Florida. Light roof colors, deck-mounted radiant barriers, added attic ventilation and tile roof construction were all shown to reduce peak attic air temperatures. A simple characterization of the collected data would be as follows:

Table 6
Comparison of Coincident Attic
to Ambient Design Temperature Difference

Case	Coincident 2.5% Attic Design Temperature
Shingle roof, soffit vent only	Ambient + 35°F (19.4°C)
Shingle roof, soffit and ridge venting	Ambient + 22°F (12.2°C)
Shingle roof, Radiant Barrier soffit vent only	Ambient + 25°F (13.9°C)
Tile roof	Ambient +10°F (5.6°C)
White roof	Ambient -1.5°F (0.8°C)

Note that this summary does not represent a statistical sample and may only be representative for Florida conditions. Even so, it is likely that the general ranking of identified influences will be observed in measurements elsewhere.

A simple calculation illustrates the importance of controlling the peak attic air temperatures measured in this study. As example, consider a residence on a a peak summer day at 95°F served by a three ton cooling system with a sensible capacity of 27,000 Btu/hr and an EER of 9.0 Btu/W. The assumed residence has a 1,800 square foot ceiling with R-30 attic insulation. Supply ducts typically comprise a combined area of ~25% of the gross floor area (see Gu et al. 1997, Appendix G, and Jump and Modera, 1994), but are only insulated to R-4. With the peak attic temperatures for a shingle roof with poor ventilation estimated at 130°F, and 75 maintained inside, a UA dT calculation shows a ceiling heat gain of 3,300 Btu/hr. With R-4 ducts in the attic and a 57 air conditioner supply temperature, the heat gain to the duct system is 8,212 Btu/hr if the cooling system ran the full hour under design conditions-- more than twice the ceiling flux. However, the magnitude of both ceiling and duct heat gain is 43% of the air conditioner's design sensible cooling load. Thus, attic heat to ceiling and attic to duct heat gains are a major portion of the design cooling load for residences.

In the example the attic related gains are also responsible for a 1.28 kW increase in peak air conditioning electric demand. As a contrast, with a white roof system, the estimated attic air temperature would be 93.5°F, with a total ceiling and duct heat transfer rate of 5220 Btu-- a reduction of 6,300 Btu/hr and a drop in electrical demand of 700 W if the system was at design capacity with the dark roof.

Acknowledgment

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1. Homestead is some 50 km south of Miami, Nobleton is in the West Central part of the state; Hollywood is just north of Miami, and Merritt Island, Palm Bay and Cocoa are on the Atlantic coastal zone in central Florida. Belle Glade is in the South Central part of the state

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