

Measured Impacts of Air Conditioner Condenser Shading

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PROCEDURE

Air temperatures, insolation and AC energy consumption were measured in three residential sites for a period of four weeks before and after the condenser was shaded. The experiments were conducted over the course of two summers. At the first site the condenser was shaded extensively with medium-tree specimen landscaping. The condenser at the second site was shaded with a site-built wooden trellis. A third site had extensive landscaping added to shade the condenser and surrounding area. Each site was an occupied residence in Central Florida which had an unshaded, west exposed air conditioner condenser.

A multi-channel datalogger recorded AC electrical demand as well as air temperatures, insolation and other weather conditions. Instruments were scanned every ten seconds with integrated values output to storage on a 15-minute basis. Temperature and solar irradiance was also collected one foot away from the condenser inlet. Figure 2 shows the installation of the temperature and insolation apparatus to collect this information by the AC condenser in one of the experiments. Temperatures were obtained using differential-voltage calibrated type-T copper-constantan thermocouples with a relative accuracy of 0.05°F (0.03°C). Special attention was given to proper shielding of air temperature probes to minimize experimental error associated with the influence of solar radiation (Sonne, et al., 1993). Insolation was measured using

two calibrated silicon cell pyranometers with a relative accuracy of 3%. One was located on the unobstructed roof top and the other placed by the outside condenser unit. Wind speed was provided by a cupped roof-top anemometer. AC power was measured using a true watt-hour transducer with a measurement accuracy of 2.0% RMS. Each evening, the data were transmitted from the measurement sites via modem to a main-frame computer. Data were then automatically plotted for review by a project engineer the following morning. A sample of the 15-minute daily data collected in the project is shown for site 1 in Figure 3 (top of the next page).

The intent of the data analysis was to compare the AC electrical use and ambient to condenser inlet temperature differences on days with similar weather conditions in pre- and post-treatment periods. Differences in afternoon solar insolation on the condenser surface would also be compared. These differences would then be used estimate the impact of condenser shading on cooling performance. An uncertainty analysis was undertaken to calculate measurement error (Kline and McClintock, 1953) as well as to evaluate experimental results to isolate statistically significant effects (Baird, 1995).

It was expected that the primary source of data for evaluation of the experimental results would be the temperature depression achieved at the condenser air inlet pre- and post-shading. From

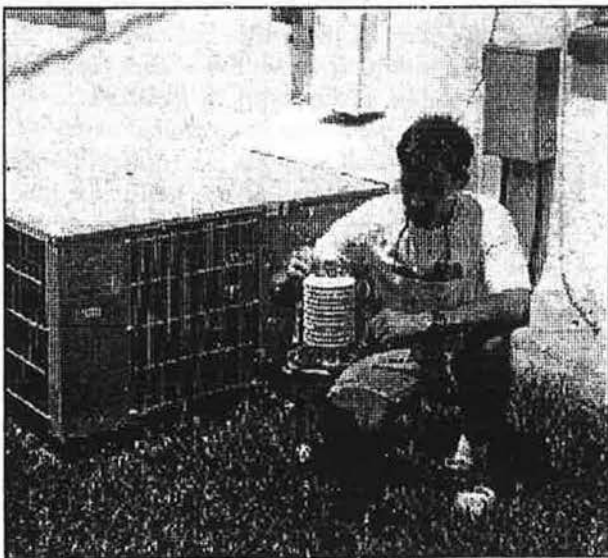


Figure 2. FSEC research engineer, Jeff Sonne, adjusts a pyranometer leveling base on the apparatus used in the measurement of condenser air and insolation conditions at site 2 (left). Example of roof top meteorological station (right).

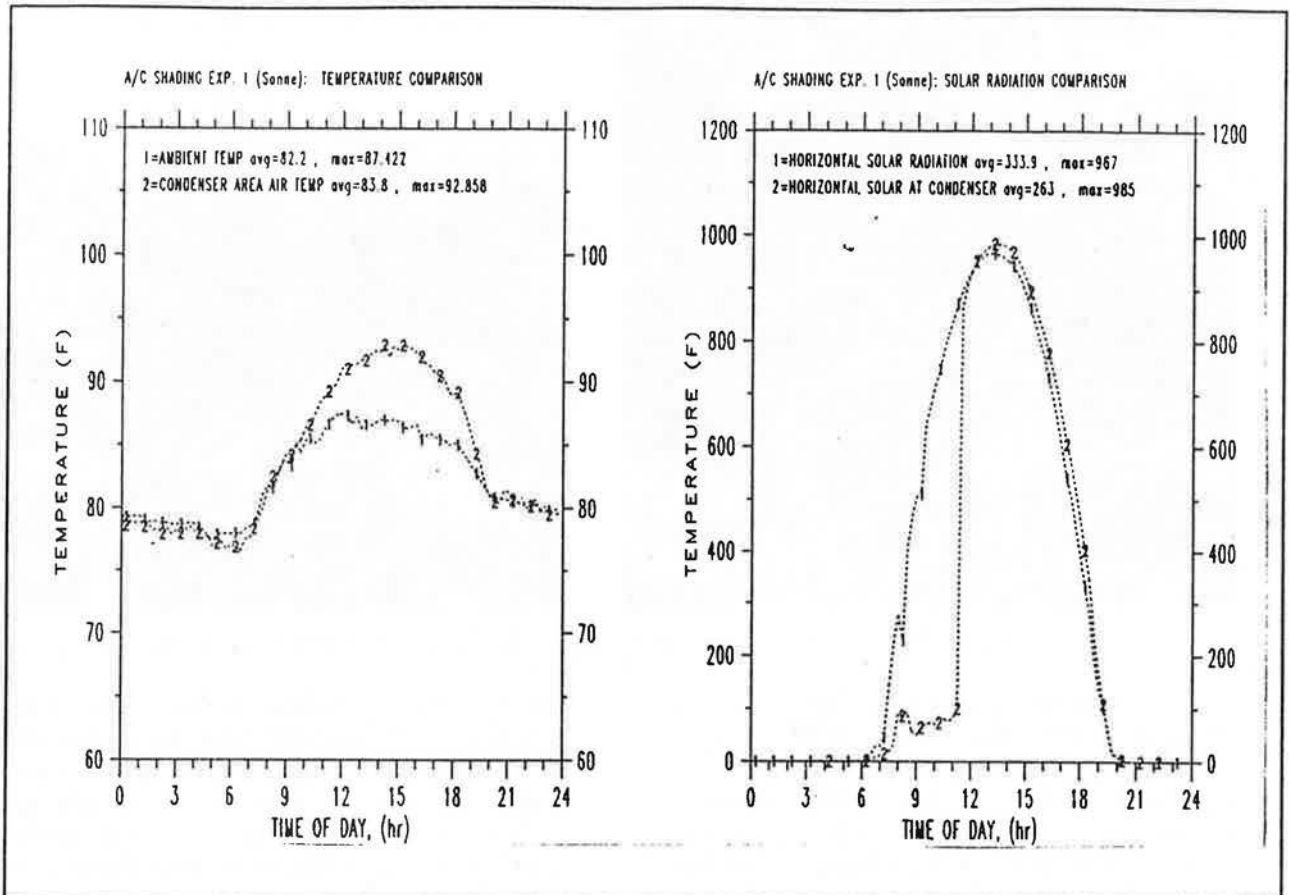


Figure 3. Sample daily 15-minute data for June 21, 1993 at site #1 during the baseline data period prior to landscape changes. Note the elevated temperature at the condenser inlet during the afternoon relative to other hours.

previous research, it was apparent that occupancy related variations (internal heat gains and door openings etc.) would make changes in measured AC electrical consumption less robust for isolating the smaller impacts of condenser shading.

RESULTS

AC condensers were shaded at mid-summer after a period of base-line data was collected. The landscaping or shading devices were installed to provide as much afternoon shade as possible, but to obstruct air flow as little as practical into and out of the AC condenser. All of the AC units were fully exposed on the west faces of the three homes. Thermostats and operation of the systems were held constant to eliminate this source of variation.

The first experiment was conducted in a single family home in Merritt Island, FL with a conditioned floor area of 1,490 ft² (138 m²). The air conditioner was a GE BTB730A166A1 2.5-ton (8.8

kWt) split system with a SEER of 7.2 Btu/w (COP=2.1). Rated condenser air flow was 3,000 cfm (1475 L/s). The home was instrumented in late May, 1993 with data then taken on roof top meteorological conditions as well as those in the immediate vicinity of the AC condenser. Landscaping was installed on July 12, 1993 after four weeks of data collection. Three trees were planted as shown in Figure 4 (top of the next page). Two of these were 8-foot (2.4 m) Wax myrtle trees (*Myrica cerifera*) and the larger specimen was a 10-foot (3.3 m) Live Oak (*Quercus virginiana*). The trees were located to provide a shade pattern with maximum afternoon coverage of the condensing unit and surrounding area, while not interfering with the upward exhaust air flow pattern. Also, a thick bed of mondo grass (*Ophiopogon japonicus*) was planted around the base of the condensing unit. The plants were automatically watered for an hour each evening to establish healthy growth and encourage transpiration cooling during daytime hours.

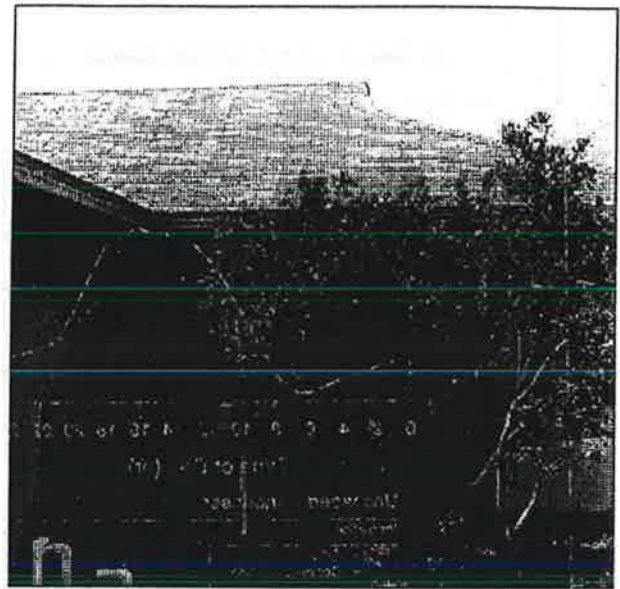
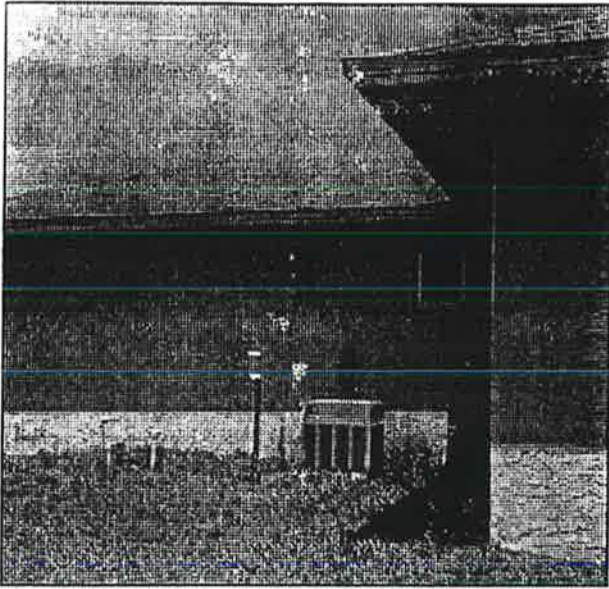


Figure 4. West-facing condenser at site 1 prior to landscaping (left). Final appearance after tree planting (right).

Using three-week pre- and post-periods with similar weather conditions (temperature and solar irradiance), a reduction in the maximum afternoon summer temperature by the condenser inlet was measured to be approximately $3.3^{\circ}\text{F} \pm 0.1^{\circ}\text{F}$ ($1.8 \pm 0.06^{\circ}\text{C}$) relative to ambient conditions at 5:15 PM. The simple average reduction over the daily cycle was $1.0^{\circ}\text{F} \pm 0.1^{\circ}\text{F}$ ($0.6 \pm 0.06^{\circ}\text{C}$). Figure 5 shows the measured ambient air and condenser temperature profile during the week before and after the landscaping was planted. Figure 6 (top of the next page)

shows the measured reduction in the temperature and insolation by the condenser from the shading when measured over two long-term periods with similar average weather conditions (ambient air temperature within 0.2°F and solar radiation within 10 w/m^2). As expected, the major differences were observed in the afternoon hours. Unfortunately, energy savings could not be measured in the experiment since the control thermostat developed a drift which lowered the interior temperature during the post treatment period and made a meaningful comparison impossible.

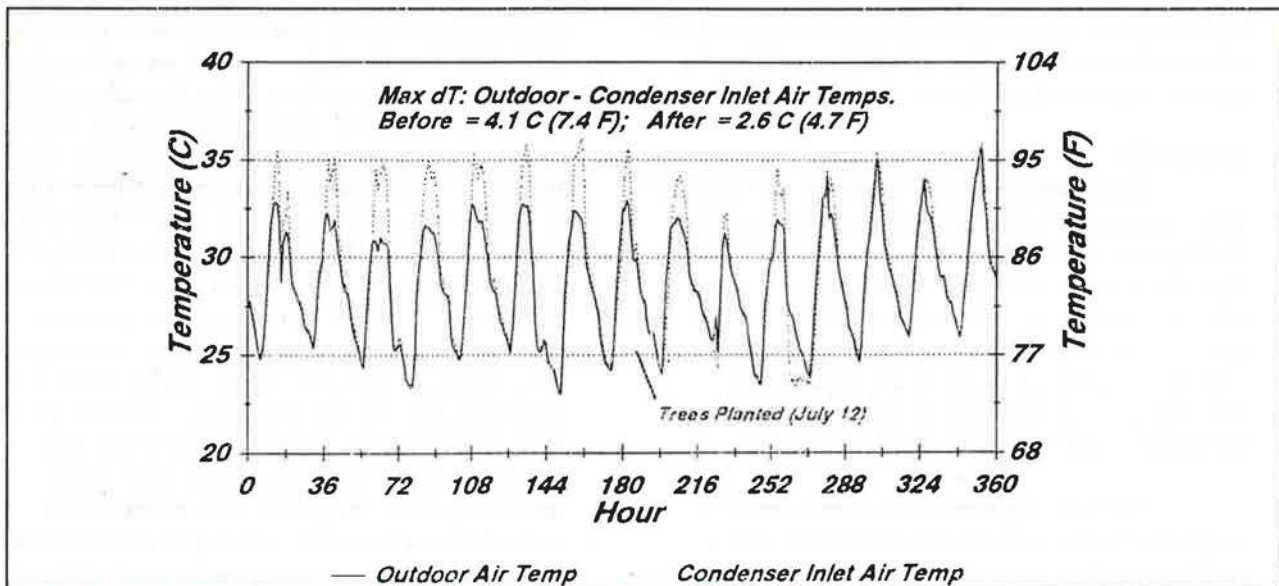


Figure 5. Measured outdoor ambient and condenser inlet air temperatures during week long periods before and after the landscaping shading was planted.

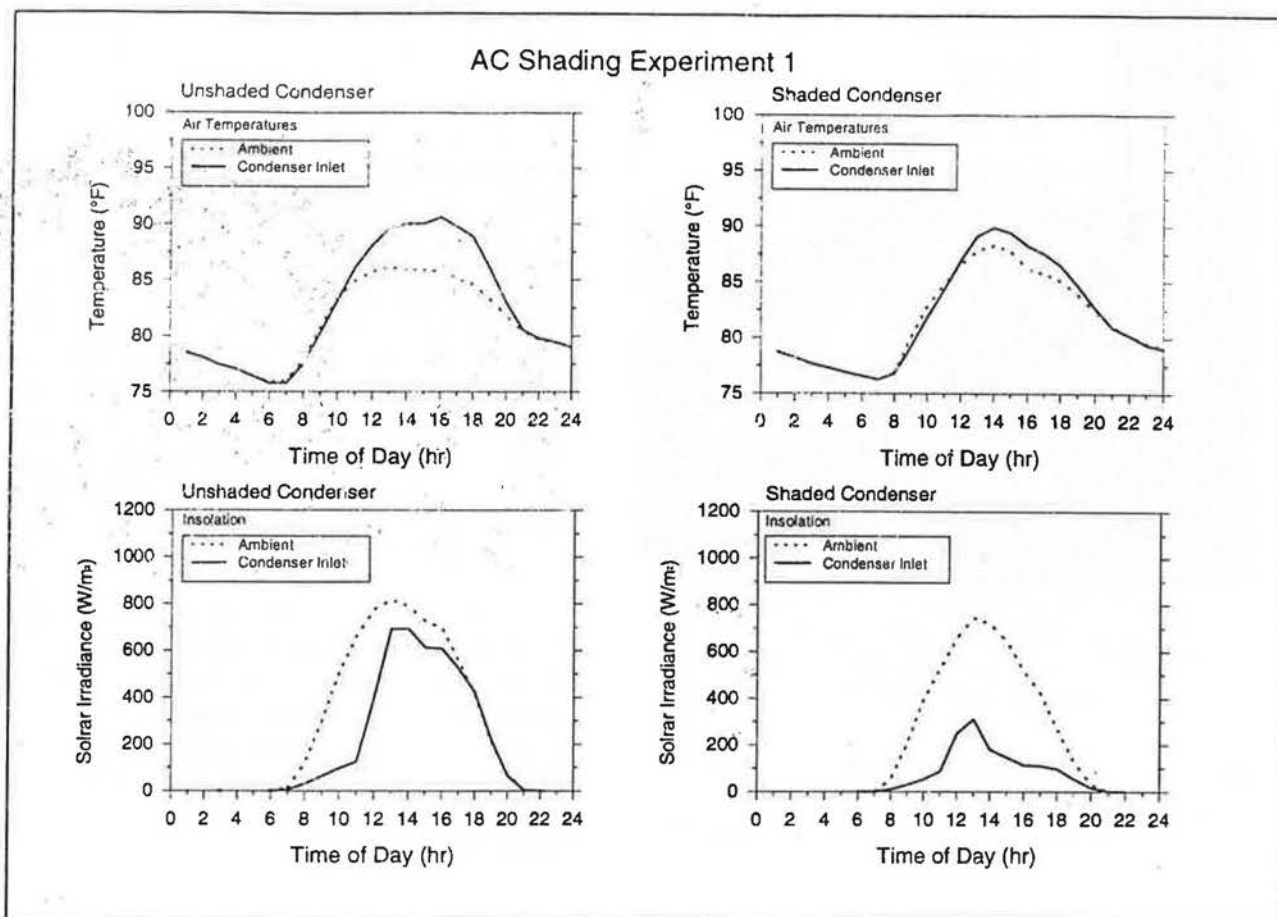


Figure 6. Plot of three week temperature and insolation profiles before and after landscaping at site 1.

A second experiment was conducted on a 1,800 ft² (167 m²) home also in Merritt Island, Florida. The air conditioner was a packaged heat pump with a rated EER of 9.9 (COP=2.9) and a cooling capacity of 29,000 Btu/hr (8.5 kW) at standard ARI conditions. The packaged unit was of particular interest because both the horizontal exhaust air from the condenser was affected sufficiently by the landscaping to produce some mixing of the exhaust and inlet airstreams, thereby increasing the input air temperature to the condenser. For this experiment a simple wooden overhead trellis was constructed to shade the packaged AC unit as commonly advocated by consumer publications (Koon, 1989). Six weeks of pre-retrofit AC and weather data were collected with the shading device installed on August 14, 1993. The inlet air was drawn from the sides and exhaust air was expelled horizontally away from the house. The inlet air temperature was not reduced significantly over the 24-hour cycle ($0.04 \pm 0.1^\circ\text{F}$ or $0.02 \pm 0.06^\circ\text{C}$).

However, a maximum difference of $0.3 \pm 0.1^\circ\text{F}$ ($0.17 \pm 0.06^\circ\text{C}$) was observed at 4:30 PM and a reduction in coincident energy use was observed when differences in weather related conditions were considered. The small energy savings may be attributable to reduced direct solar gain to the air handler section of the packaged unit which was exterior to the house and directly exposed to the sun. The configuration is depicted in Figure 7.

In the third experiment, landscaping was again extensively used. The test was performed in the summer of 1994 on a 1,700 ft² (158 m²) single family home on Merritt Island. The air cooling system was an older packaged 3-ton (10.6 kW) heat pump with an approximate SEER of 7 Btu/W (COP=2.1). The unit was located on the west side of the home as shown before and after landscaping in Figure 8 (bottom of the next page). Four 8-foot (2.4 m) Crape Myrtle (*Lagerstroemia indica*) trees were planted on July 11th. The plants were situated

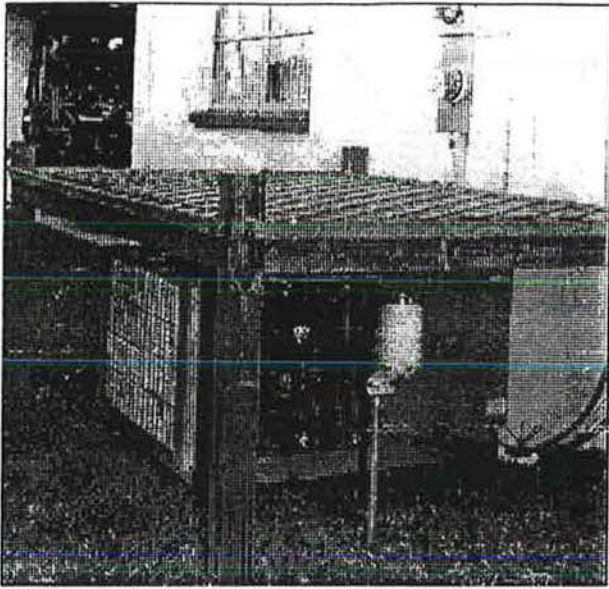


Figure 7. Trellis shading device built over the condenser at site #2. The packaged unit draws air through inlets on each side and exhausts air horizontally from the house.

to provide maximum afternoon shade of the AC condenser unit while particular care was taken to ensure that neither intake nor exhaust air flows were

impeded. An automated watering system was set up to provide drip irrigation during evening hours.

However, contrary to the previous experiences, the temperature around the condenser rose above ambient ($0.7 \pm 0.1^\circ\text{F}$ or $0.4 \pm 0.06^\circ\text{C}$) after the landscaping was installed. The difference was greater between 12 and 6 PM ($0.9 \pm 0.1^\circ\text{F}$ or $0.5 \pm 0.06^\circ\text{C}$). Controlling for before and after weather conditions, air conditioning electrical consumption also rose by over 15%. The magnitude of this change is much larger than expected and is still unexplained. In spite of the attention to maintain free air flow, we speculate that the horizontal exhaust air from the condenser was affected sufficiently by the landscaping to produce some mixing of the exhaust and inlet airstreams, thereby increasing the input air temperature to the condenser.

Table 1 (top of the next page) summarizes the results obtained from the three experiments. Reductions to temperature and insolation are those measured near the condenser relative to those measured at the roof-top meteorological station. AC savings are not available for site 1 due to the problem associated with the thermostat control during the post treatment period.

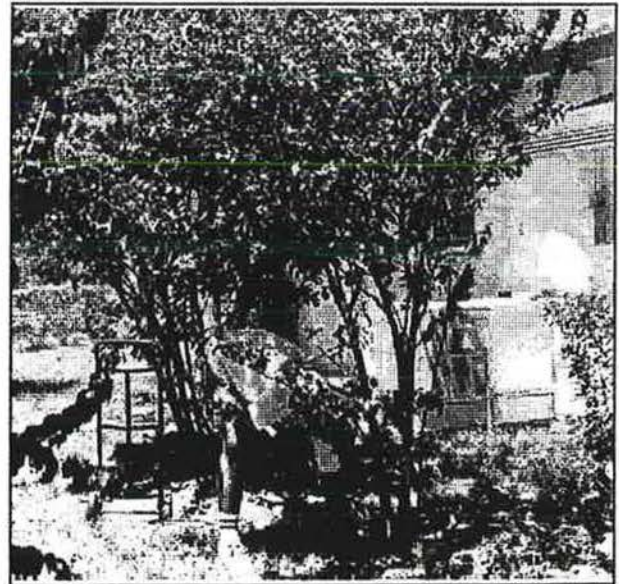
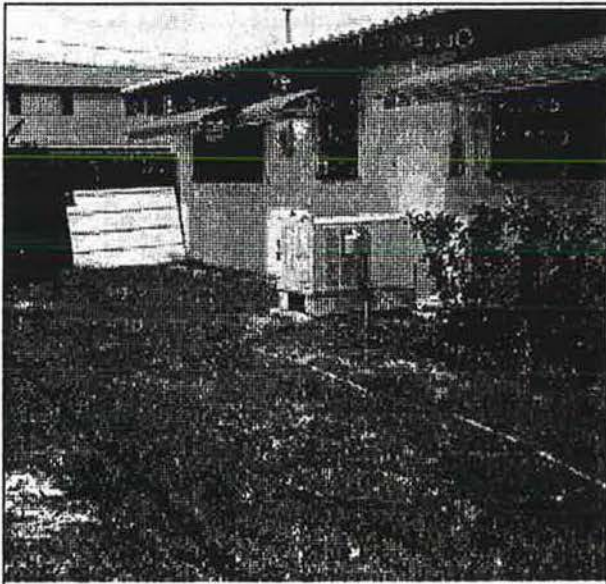


Figure 8. West-facing AC condenser shading at site 3 before landscaping (left). Planting of four Crape Myrtles for shading (right).

Table 1
Measured Effect of Air Conditioner Condenser Shading

Site (Shading Method)	Temperature Reduction (°)		Insolation Reduction (W/m ²)	Air Conditioning Savings Average Watts, (%)	
	24 hr	12-6 PM		24 hr	12-6 PM
1 (Landscape)	0.97 ± 0.1°F 0.54 ± 0.06°C	2.62 ± 0.1°F 1.46 ± 0.06°C	377±18	NA	NA
2 (Trellis)	0.04 ± 0.1°F* 0.02 ± 0.06°C	0.08 ± 0.1°F* 0.04 ± 0.06°C	351 ± 15	36 ± 32W, (3%)	124 ± 53W, (6%)
3 (Landscape)	-0.66 ± 0.1°F 0.37 ± 0.06°C	-0.92 ± 0.1°F 0.51 ± 0.06°C	203 ± 6	-260 ± 28W, (-18%)	-340 ± 46W, (-15%)

* Not statistically significant (p>0.1)

DISCUSSION

The probable explanation for the lower than expected performance in the experiments is that outdoor AC units draw in a volume of air that greatly exceeds that of the nearby shaded air volume. Air-cooled condensers move a quantity of 600 - 1200 cfm of air per ton (80-160 L/s/kW) of cooling capacity (ASHRAE, 1992). For instance, a typical 3-ton (10.6 kW) air conditioner's 300-W condenser fan would draw 2,800 cfm (1321 L/s) of air at a very low static pressure across the coil (Proctor et al., 1994). Thus, the unit would process 168,000 cubic feet (4.76 x 10⁶L) of air per hour. Assuming no mixing, this would represent a volumetric equivalent to a cube of air with sides measuring 55 feet (16.8 m).

Although shading a much larger area may produce better results, our limited data indicate that average daily condenser air inlet peak temperatures can be reduced by as much as 1.0°F (0.6°C) from localized landscape shading or conversely increased by as much as 0.7°F (0.4°C) from an unsuccessful installation. The largest reductions were seen in the late afternoon hours at site 1 with an average peak difference between ambient and condenser inlet air temperature conditions of 3.3 ± 0.1°F (1.8 ± 0.06°C). Based on both measurement and a theoretical analysis, devices which only provide direct shade for the AC condenser cannot be expected to lower the average AC inlet temperature by more than 0.2°F (0.1°C).

Analysis of current generation air conditioning equipment indicates an increase in air conditioning efficiency of approximately 1.2% per °F (0.7% per°C) reduction in condenser inlet

temperature. The most optimistic assessment, based on the positive results at site 1, are of a 1% improvement in summer air conditioner efficiency. On the other hand, the computed sample average AC savings produced by our three experiments was 0.1% (± 2.0%). As suggested by the uncertainty in the above estimate, our measurements did not allow us to conclusively determine that AC condenser shading, when limited to the immediate area surrounding the condenser unit, provides statistically consistent reductions to cooling energy use. We believe the mixed results reflect the limited potential of the measure.²

Our experience also illustrates the hazards of localized condenser shading, underscored by the poor results achieved in these experiments relative to the careful planning involved. Planting trees and shrubs close by a condenser may actually reduce system efficiency due to impedance of effective air movement.

We conclude that any savings produced by localized AC condenser shading are quite modest (<3%) and that the risk of interrupting air flow to the condenser may outweigh shading considerations. The preferred strategy may be a long-term one: locating AC condensers in an unobstructed location on the shaded north side of buildings and depending on extensive site and neighborhood-level landscaping to lower localized air temperatures.

² It seems unlikely that AC condenser shading can be cost justified on the basis of energy savings. The installed cost of the installed landscaping at site 1 was \$569 and \$440 at site 3. The materials for the shading trellis at site 2 cost approximately \$40, although allowance should be made for the five hours labor necessary for its construction.

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APPENDIX

Air Flow Patterns and AC Condenser Performance

In attempting to understand why the shading of AC condensers may not provide the benefits envisioned by others, we discovered a possible opportunity for improving air conditioner efficiency which has been little quantified. Our results underscore the importance of establishing unobstructed air flow from air cooled condensing units. Given the close proximity of the inlet and exhaust flow areas of residential air cooled condensers, it is important to insure that the exhaust air plume projects cleanly away from the unit. For condenser units with top exhaust, the exhaust air flow is extremely turbulent (characterized by high

Reynolds numbers), but sufficiently rapid to reach conditions of reasonable throw at exit. However, as with most fan flows, the exhaust air flow pattern is not fully developed at the point of exhaust and can be strongly affected by surrounding building geometry.

Recent FSEC experiments using colored smoke candles for flow visualization, suggest that even small obstructions in the exhaust jet may easily induce eddy currents in the flow vortex which result in recirculation of air from the exhaust to condenser inlet. For optimal performance, the results suggest that AC condensing units should be located several feet away from overhangs, vegetation or other obstructions that would impede or deflect the exhaust air flow. Although AC manufacturers commonly specify minimum clearances for condensing units away from walls and overhead obstructions, the experiments so far conducted indicate that these values may be based more on practicality than for providing optimal performance.

