

Measured Impacts of Air Conditioner Condenser Shading

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ABSTRACT

A previous EPA study had recommended shading of exterior air conditioner condensers, using landscaping or other means, as a method to reduce space cooling energy use (Akbari et al., 1992). An additional study has been conducted by the Florida Solar Energy Center (FSEC) to quantify the space cooling energy savings from shading condenser units. The investigation consisted of before-and-after experiments conducted on three homes over a two-year period.

Background

Air-cooled condensers, as commonly used in residential air conditioning systems, employ finned-tube construction to transfer heat from the refrigerant to the air. As hot, high pressure refrigerant passes through the coil, heat in the compressed refrigerant is transferred through the tubes to the attached fins. Fans are then used to draw large quantities of outside air across the finned heat transfer surfaces to remove heat from the refrigerant so that it will be condensed and partially sub-cooled prior to its reaching the expansion valve. In theory, the efficiency of vapor compression air conditioning can be improved through two primary mechanisms associated with condenser shading:

- Direct shading: incident solar radiation can pose approximately a 1,000 W/m² load under peak summer conditions to the exposed condenser surface.
- Temperature depression: the presence of the shade trees or shading devices can potentially reduce localized outside air temperature (through direct shading and/or evapotranspiration) and hence drop the inlet air temperature to the condensing unit.

Estimated savings from air conditioner condenser shading with landscaping have varied from 2 - 10%. The range of the estimates has largely to do with the assumed depressions that could be achieved for the inlet air to the AC condenser. Abrams (1986) speculated that reductions of 1-2°F (0.6-1.1°C) could be achieved. Parker (1983, 1989) assumed that large trees could provide effective shade not only to the air conditioning condenser, but also to the adjacent areas and reduce ambient air temperatures by up to 7°F (3.9°C). Field measurement in the same studies showed measured reductions to air temperatures near shrubs and trees of 4-6°F (2.2-3.3°C), albeit under still air conditions. More extensive landscaping may have larger effects. Geiger (1957) found up to 9°F (5°C) differences between peak temperatures in heavily forested sites, versus those in open terrain and without shade. Measurements in suburban areas have shown 4-6°F (2.2-3.3°C) peak differences between neighborhoods under mature tree canopies and newer developments with no trees (McGinn, 1982). However, still another investigation of the effect of small groups of

trees on localized microclimate (Heisler, 1977) showed only small reductions to ambient air temperature (<2°F or 1.1°C), likely due to air movement. None of the studies considered the impact of landscape shading on air temperatures entering a system, such as an air conditioning condenser, which is designed to move a large volume of air over time.

Application of the first law of thermo-dynamics to Carnot's theoretical performance of an ideal air conditioner immediately suggests the importance of reducing the high temperatures to which heat is rejected in the refrigeration process:

$$\text{COP} = \frac{T_2}{(T_1 - T_2)}$$

Where:

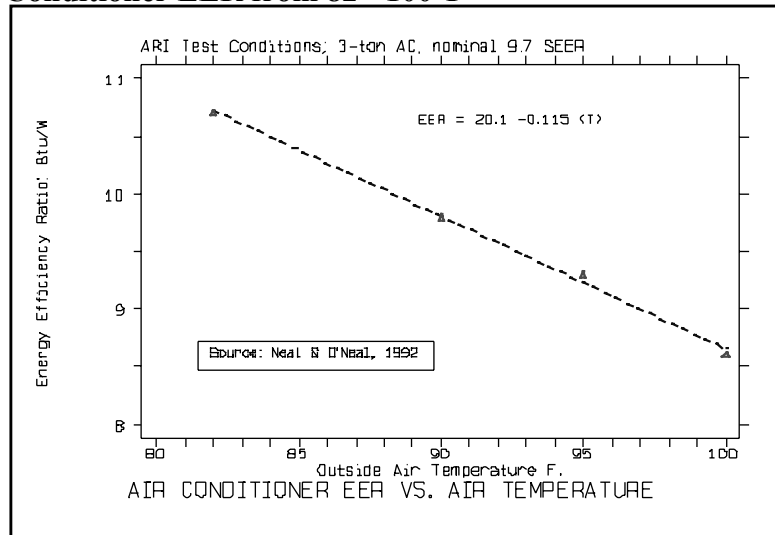
- COP = Coefficient of performance
- T₁ = absolute temperature of the working fluid in the condenser at which heat is rejected to the atmosphere (°K)
- T₂ = absolute temperature of the refrigerant at which heat is absorbed from the house interior (°K)

In residential air conditioners an evaporator refrigerant temperature of 45°F (280°K) is common. Assuming a peak summer outdoor temperature of 95°F (308°K) and a 25°F temperature difference between the condensing and heat sink, yields a typical condensing temperature of 120°F (322°K). Thus, the theoretical maximum COP for such an air-cooled cycle can be shown to be 8.1.¹ Further manipulation of this equation shows that the machine's COP can be theoretically improved by about 1.4% for each degree °F that the outdoor heat sink temperature can be lowered.

The situation is somewhat different for real air conditioners, however, since the simple analysis above assumes a constant compressor efficiency and refrigerant pressure drop, as well as no friction losses or inefficiencies in the compression and expansion process. These factors serve to reduce achievable performance. Air conditioner performance in the U.S. is commonly rated as energy efficiency ratio, or EER, rated in Btu of heat rejection per input watt of power demand (COP = EER/3.413 Btu/W). Generally, the EER of residential air conditioners drops by about 1.2% per each degree F° (0.6°C) that the outside air temperature increases over the range between 82°F and 100°F (27.8 and 37.8°C) (Neal and O'Neal, 1992). Figure 1 illustrates this effect from the test results for a standard residential unit. The unit is a nominal 3-ton unit with a Seasonal Energy Efficiency Ratio (SEER) of 9.7.

¹ Obviously, efficiencies in typical air conditioners are subject to limitations of the vapor compression cycle as well as motor efficiencies for the compressor, condenser and evaporator fan drives that degrade performance to levels considerably lower than indicated by the ideal Carnot cycle.

Figure 1. Influence of Outdoor Temperature on Air Conditioner EER from 82 - 100°F



The implication for condenser shading is clear: overall efficiency of typical residential units can be improved by about 1% for each °F or 1.8% per °C that the condenser inlet temperature can be lowered.

An additional complication arises from the need to quantify the impact of solar irradiance directly on the exchange surfaces of the condensing unit. Although the peak solar intensity may be approximately 1,000 W/m², the required condenser air flows which are greater than 600 cfm per ton (>80 L/s/kW_t) will tend to reduce the importance of this effect. For instance a typical 3-ton condenser will process 170,000 cubic feet (4.81 x 10⁶L) of air per hour with a total density-specific heat product of 3,060 Btu/°F (174 kJ/°C). If a condenser exposed to mid-afternoon insolation at 1000 W/m² over a 4 ft² (0.4 m²) surface with an absorptance of 80% could be shielded from two-thirds (67%) of the incident solar radiation by landscaping, the inlet air temperature depression to the condenser at the afternoon peak would only be 0.2°F (0.1°C).

Simulating the potential impact of these effects is difficult. Firstly, the change in the direct solar influence is inexact given the complex shade pattern of plants and the practical concern of locating specimens close by the outdoor unit without interfering with its air flow. Even more problematic is determination of the ability of localized landscaping to impact the microclimate at the AC condenser inlet. Although the mechanisms through which plants provide cooling are well understood, the actual impact on building level microclimate is complex. Meier (1990) has reviewed empirical studies in a pertinent summary of the literature and Huang et al. (1986, 1990) have simulated most of the major influences of landscaping on building energy use. However, an extensive search failed to uncover any empirical research into the specific issue of AC condenser shading. In spite of the lack of verified performance data, the recommendation to shade air conditioner condensers is often repeated and widely perceived as beneficial (FPL, 1989).

Procedure

Air temperatures, insolation and AC energy consumption were measured at three residential sites for a period of four weeks before and after the condenser was shaded. Thermostat setpoints and operation of the systems at each house were held constant to eliminate this source of variation. 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. The landscaping or shading devices were installed to provide as much afternoon shade as possible, but to obstruct airflow as little as practical into and out of the AC condenser. Each site was an occupied residence in Central Florida that 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 were 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 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).

Figure 2. A Research Engineer 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)



Insolation was measured using two calibrated silicon cell pyranometers with a relative accuracy of 3%. One was located on the unobstructed rooftop and the other placed by the outside condenser unit. Wind speed was provided by a cup rooftop 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 mainframe computer. Data were then automatically plotted for review by a project engineer the following morning.

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 were also compared. These differences were then used to 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 most useful source of data for determining the experimental results would be the temperature depression achieved at the condenser air inlet pre- and post-shading. From 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.

Site 1 Results

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 2.5-ton (8.8 kWt) split system with a SEER of 7.2 Btu/w (COP=2.1). Rated condenser airflow 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 3. 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 3. 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 4 shows the measured ambient air and condenser temperature profile during the week before and after the landscaping was planted. Figure 5 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 that lowered the interior temperature during the post treatment period and made a meaningful comparison impossible.

Figure 4. Measured Outdoor Ambient and Condenser Inlet Air Temperatures During Week Long Periods Before and after the Landscaping Shading was Planted

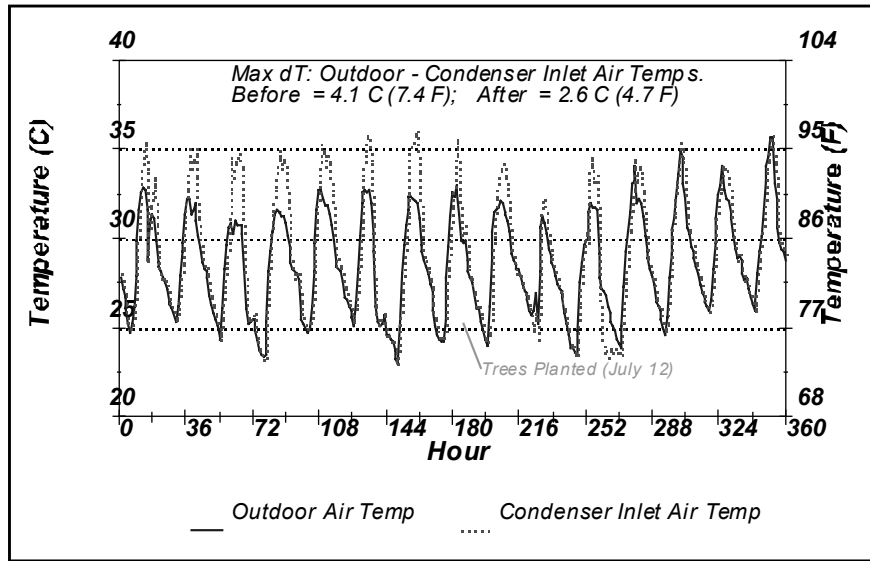
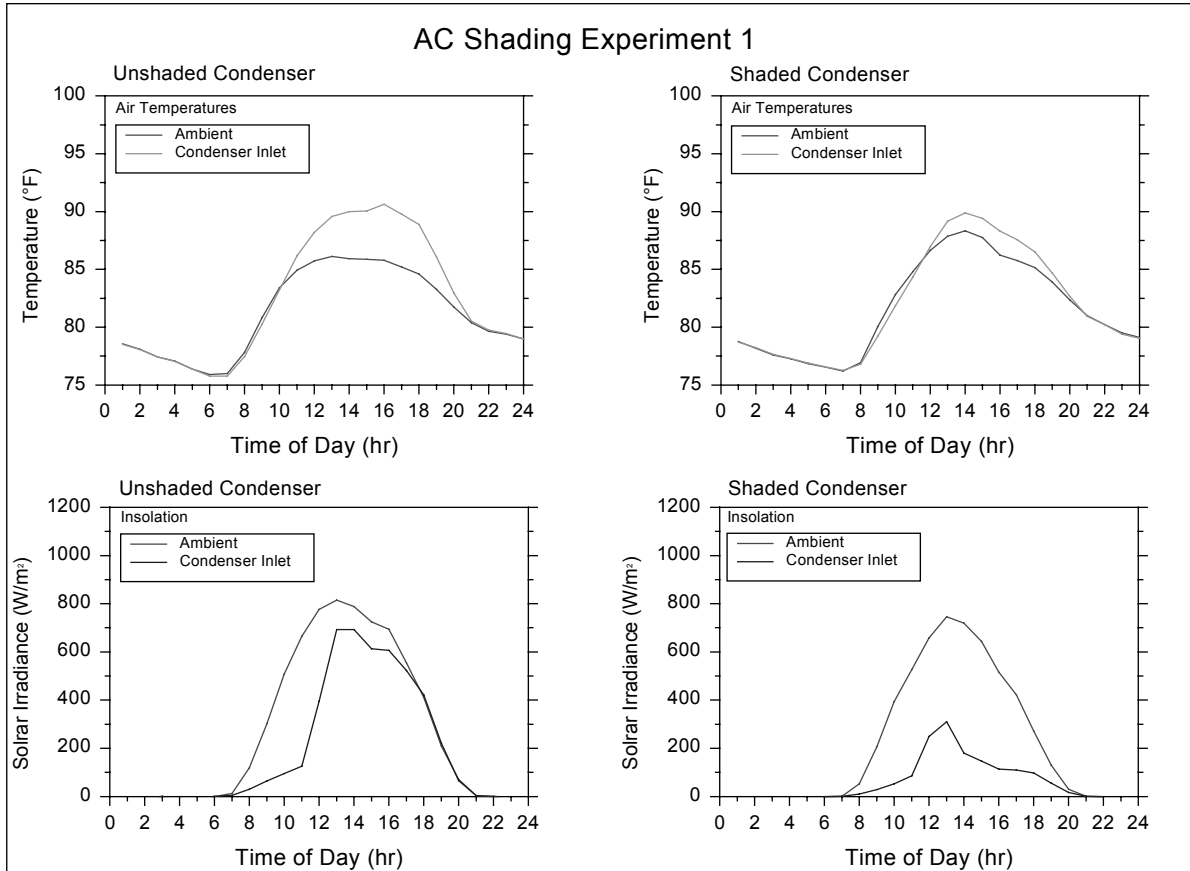


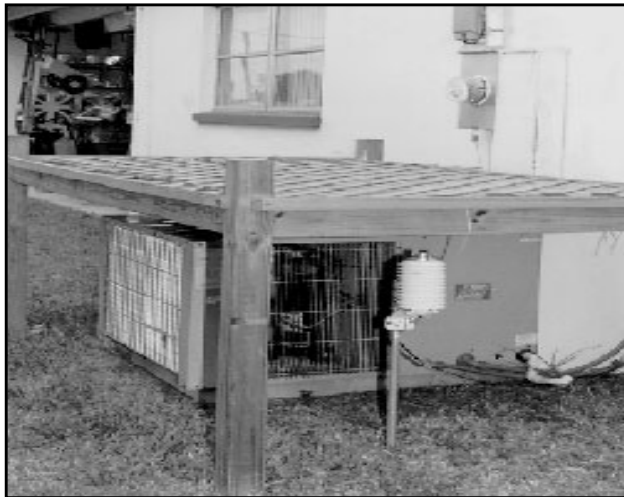
Figure 5. Plot of Long-Term Temperature and Insolation Profiles Before and after Landscaping at Site 1



Site 2 Results

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_t) at standard ARI conditions. The packaged unit was of particular interest because 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 shown in Figure 6. The packaged unit draws air through inlets on each side and exhausts air horizontally, away from the house.

Figure 6. Trellis Shading Device Built over the Condenser at Site #2



Site 3 Results

In the third experiment, landscaping was again extensively used. The test was performed in the summer of 1994 on a 1,700ft² (158 m²) single family home on Merritt Island. The air conditioning system was an older packaged 3-ton (10.6 kW_t) 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 7. Four 8-foot (2.4 m) Crape Myrtle (*Lagerstroemia indica*) trees were planted on July 11th. The plants were situated to provide

maximum afternoon shade of the AC condenser unit while particular care was taken to ensure that neither intake nor exhaust airflows were impeded. An automated watering system was set up to provide drip irrigation during evening hours.

Figure 7. West-facing AC Condenser Shading at Site 3 before Landscaping (Left); Planting of Four Crape Myrtles for Shading (Right)



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 $0.5 \pm 0.06^{\circ}\text{C}$). Normalizing for before and after weather conditions, air conditioning electrical consumption 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 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 rooftop meteorological station. AC savings are not available for site 1 due to the problem associated with the thermostat control during the post treatment period.

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 600 - 1200 cfm of air per ton (80-160 L/s/kW_t) of cooling capacity (ASHRAE, 1992). For instance, a typical 3-ton (10.6 kW_t) 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 that 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, is 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 potential hazards of localized condenser shading, underscored by the poor results achieved in these experiments even though careful planning

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.

was 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 airflow 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.

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