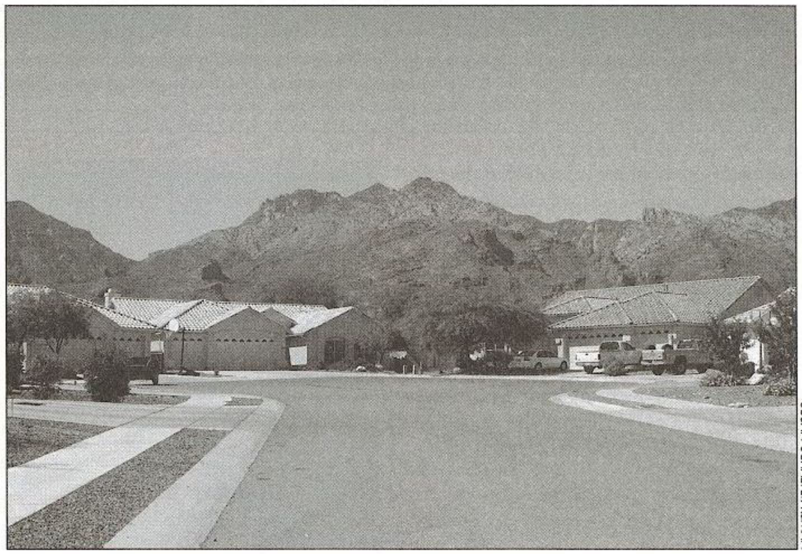
Effects of Vegetation on Residential Energy Consumption

Maybe what we think about trees, shading, and energy efficiency isn't quite true.

by Susan Schaefer Kliman and Andrew C. Comrie



SUSAN SCHAEFER KLIMAN

Several studies have suggested that trees can dramatically reduce residential energy consumption. The type of vegetation—ground cover, shrubs, trees, or a combination thereof—and the proximity of the vegetation to the structure, will determine how much shade is cast on the home throughout the day, and how much evapotranspiration will occur around the home. And the orientation of the building, along with the configuration of the vegetation, will affect that building's energy consumption. But what are the actual savings that a homeowner living in a hot-dry climate can reasonably expect in return for planting some trees and other vegetation around his or her home? This question has never been definitively answered.

In the last 15 to 20 years, several studies have attempted to quantify the impact of vegetation on the energy consumption of buildings. Urban climatologists and those involved in urban forestry have generally conducted the research. Scientists at the Center for Urban Forest Research in Davis, California, have been studying the structure of urban forests and quantifying the benefits and costs of urban vegetation. Virtually all of this research has been conducted with computer simulations, but it has yielded some promising results regarding the benefits of vegetation—particularly trees—in reducing residential energy consumption.

A 1989 study by Gregory McPherson and Eileen Dougherty estimated that for homes located in Tucson, Arizona, planting shade trees could reduce annual energy costs by 2%–11% for 1980s frame construction, and 2%–9% for 1950's type masonry construction. Studies conducted in 1995 by Gregory McPherson and James R. Simpson (see "Shade Trees as a Demand-Side Resource," *HE* Mar/Apr '95, p. 11) and in 1998 by Gregory McPherson, et al. also documented the energy benefits of reduced solar radiation on buildings.

More than one study has found that winter energy consumption is increased when vegetation blocks the advantageous solar radiation; however, these studies found that in southern and coastal climates, the summer savings far exceeded the winter penalty.

An Empirical Study

In a departure from the methodology of the previous studies, we conducted an empirical study of 105 existing homes in the metropolitan Tucson area. The study examined and quantified the actual relationship between vegetation and residential energy consumption in a hot-dry environment. The study homes were a mix of masonry (high-mass) construction, generally built between 1930 and the late 1970s, and frame-and-stucco (low-mass) construction, generally built in the 1980s and 1990s.

Data were collected from a variety of sources in an effort to obtain as much information as possible about the study homes. Homeowner surveys collected information about the physical structure. This included type of construction, age, size, and color of the house; type of heating and cooling equipment; any amenities that would affect energy consumption (such as pools and spas); and type of thermostat (programmable or nonprogrammable). Homeowners were asked to document the number of hours the house was occupied during a typical week and weekend. They were also asked to document their typical daytime and nighttime thermostat settings for both summer and winter (see "Thermostats Matter," p. 40). This information included whether they adjusted the thermostat or mechanical equipment when the home was not occupied, and if so, how.

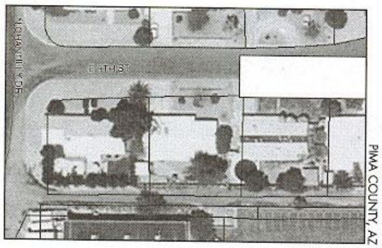
The final section of the survey pertained to landscaping. Homeowners were asked to complete a matrix of typical landscape materials and the four cardinal directions to document the landscape around their home. They were also asked to provide a simple sketch of the home and adjacent landscape, including the location of the front door and the orientation of the house.

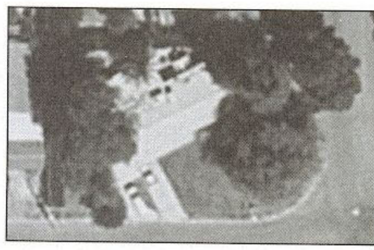
We did not document information about the homes' windows. Given the number of homes in the study, it was not feasible to visit each home to quantify the number, size, and energy efficiency of each window, or to rely on the homeowners to accurately document this information. In general, however, the number and size of the windows is inversely correlated with the age of the home. Although the newer homes in the study were often the same size as the older homes, the newer homes tended to have larger, but more efficient, windows. In the regression analysis, the age of the home serves as a proxy for the windows.

Table 1. Average Impact of Landscaping Features on Home Walls

Trees (%)				Shrubs (%)				Grass (%)				Dec. Granite (%)				Natural Desert (%)				Concrete (%)				Asphalt (%)			
N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
31	32	36	39	24	27	26	23	13	8	17	9	28	26	26	23	49	44	46	47	13	12	19	12	5	4	5	8

Note: The average exposures of the houses are based on a linear estimate of the percentage of the wall influenced by shading, transpiration, reflection, and so on.


PIMA COUNTY, AZ


PIMA COUNTY, AZ

Aerial photos were used to estimate the impact of vegetation and other landscaping features on homes.

Records from the office of the Pima County assessor were used to confirm the type of construction, age, and size of the homes. Aerial photos were also obtained from Pima County. These photos were used to estimate the impact on the home of vegetation and other landscape materials (see photos). The impact was scored by exposure on a linear scale from 0 to 100; a home with no vegetation, or with vegetation far from the structure, was rated 0, and a home with dense trees close to the structure was rated 100. The impact of vegetation on the home was assessed with respect to evapotranspiration and shading. (Table 1 shows the averages for each of the landscaping variables.)

Data on historical energy consumption were obtained from both Tucson Electric Power and Southwest Gas Corporation. A two-year history, from January 1999 through March 2001, was obtained for each house included in the study.

Finally, in order to confirm that the two years of the study were typical climate years, data were obtained from the National Climate Data Center (NCDC, 2001) and the Arizona State climatologist (State of Arizona, 2001). These data included average monthly maximum and minimum temperatures based on the period from July 1948 through December 2000, as well as average monthly temperatures for the period of the study.

All of the data pertaining to the study homes were analyzed using a series of statistical procedures to determine the effect of building construction, occupant behavior, and landscaping on the building's energy consumption for both heating and cooling. This analysis consisted primarily of a series of multivariate regressions. These regressions were performed in order to normalize the data and isolate the impact of each of the variables. For each house, values were computed for the total energy consumption for the study period as well as for annual energy consumption, based on space conditioning energy use alone. The homes used for the study all had gas heat and electric cooling. By looking at electric usage during the winter months and gas usage during the summer months, it was possible to determine monthly baseline gas and electricity usage.

Tucson also has distinctive shoulder seasons in the spring and fall when no heating or cooling is used, and all energy consumption is considered baseline usage. When that baseline usage was removed for each month, it was possible to determine the gas and electric use attributable to space conditioning alone. The results were grouped according to

Thermostats Matter

Thermostat settings were a very important measure of energy consumption for cooling. Depending upon the climate pattern for the year, the summer cooling season can start in May or June and run through August or September. On average, for every °F that thermostat settings were increased during summer nights, the summer cooling load dropped by 119 kWh (2.8% of average annual cooling load). It is unclear why the summer nighttime thermostat settings were a predictor and summer daytime thermostat settings were not. It is possible that this result has something to do with the habits of the occupants.

Among homes with air conditioning, 69% of the occupants adjusted the thermostat to make the house warmer when they were not home, and 3% actually turned the unit off. For homes with evaporative cooling, 37% of the occupants adjusted the thermostat to a higher temperature when they were not at home, and 37% turned the unit off. In fact, the savings for occupants who turned off their cooling units when they were not home was significant, at 1,198 fewer kWh per year (28% of average). Thermal lag is also a likely factor. While the daytime thermostat settings were more important in the winter, the reverse was true in the summer. Regardless of the season, the thermal lag causes heat to be radiated into the house long after the sun has set. This additional heat input probably affects the nighttime thermostat settings, and overall nighttime energy consumption during the cooling season.

whether there was a positive or negative correlation between a given variable and energy consumption. We were primarily interested in the landscaping variables—vegetation and hardscaping, such as sidewalks, brick and concrete patios, driveways, and decomposed granite.

SUSAN SCHAEFER KLIMAN

Typical new construction in Tucson subdivisions has little vegetation.

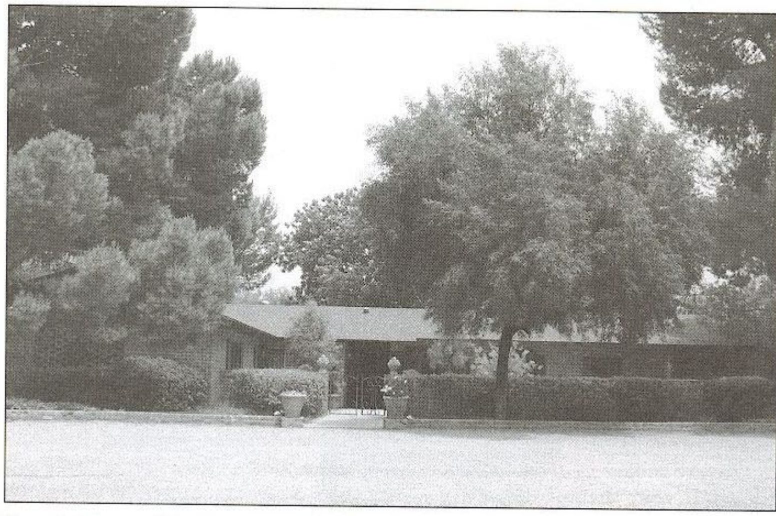
Some Surprises

The analysis yielded some predictable as well as some surprising results. Most of the study houses were not landscaped with heavier vegetation on southern and western exposures; homeowners tend to landscape with aesthetics—not energy savings—in mind. The landscaping patterns of the study houses indicate that roof shading from trees is not typical for residential landscaping in Tucson—the trees used in landscaping generally don't grow this large. Statistical analysis showed no significant correlation between the orientation of the vegetation and energy consumption, except in the case of the eastern exposure in the winter. In this instance, the effects of the vegetation were deleterious, not advantageous, to energy consumption.

Homes that were landscaped with decomposed granite on the southern exposure had a strong negative correlation with the winter heating load. In other words, the more decomposed granite there is on the southern exposure of the house, the lower the winter heating load. This probably happens because the dark-colored high-mass decomposed granite absorbs heat. The added heat on the south side of the house, where the winter sun shines the most, would reduce the temperature gradient on that side.

On the other hand, several landscaping variables increased the winter heating load. The increased load is not unexpected, although it is a bit complex to explain. In general, vegetation should increase the winter heating load. There are two reasons why. First, very little vegetation in Tucson is truly deciduous. This means that the vegetation is blocking the advantageous sun in the winter, particularly on the east and south sides of the house. Second, the vegetation is transpiring to some degree, even in the winter. The evaporation of this moisture in the winter actually increases the temperature gradient between the exterior and interior temperatures—which, in turn increases the heating load. This situation is particularly harmful on the eastern exposure, since the coolest temperatures occur just before sunrise.

The goal in reducing the heating load is to warm up the house as quickly as possible in the morning. Creating cooler temperatures on the east side of the house counteracts this strategy. This finding was consistent with several previous computer simulation-based studies.


SUSAN SCHAEFER KLIMAN

We noticed that established Tucson neighborhoods were heavily vegetated.

There were no landscaping variables that decreased the summer cooling load. This result was a surprise. We had expected that trees would decrease the summer cooling load, at least to some extent. In fact, none of the vegetation variables for either a single exposure or the total value decreased the summer cooling load. However, the data show that the density of vegetation and the percentage of shading on the walls of the study homes is quite low, with an average value of just over 30%. It is not possible from this sample to say with statistical certainty that a heavily shaded sample would show different results; however, the vegetation around the houses in the study sample was clearly inadequate to reduce cooling energy use.

There were a few landscaping variables that increased the summer cooling load. Trees on the northern exposure, and high total number of trees, slightly increased the summer cooling load. Previous simulation studies have documented a reduction in air infiltration due to the sheltering effects of the vegetation. This reduction is desirable in a cold climate in the winter; however, research has shown that while the vegetation barriers may reduce the infiltration of warm air, these barriers often trap heat against the building. It is possible that this trapping effect was significant in the study homes. For certain exposures, the typical landscaping pattern traps so much heat that it exceeds the shading benefit from the vegetation. These results imply that actual landscaping conditions are such that the potential savings documented in the computer models are not being realized.

Although only 28% of homes had asphalt driveways, this variable was significantly correlated with an increase in the cooling loads for the eastern, western, and total exposures. There were several reasons for this correlation. Asphalt is a high-mass material, and it is dark. This means that it absorbs and retains heat, which is then reradiated throughout the day and the following night. The increased temperature gradient results in an increased cooling load. This is particularly important on the eastern and western exposures. On the eastern exposure, this heating would begin at the start of the day and begin to heat the home early. On the western exposure, the augmented heating of the air would occur at the warmest part of the day.

Of the variables that we studied, one of the most important with regard to annual cooling load was the size of the house. The results were the same regardless of the type of construction. Another critical factor was whether the house was cooled with air conditioning or evaporative cooling. The energy load on a house is independent of the type of mechanical equipment. But an air conditioner uses more energy than an evaporative cooler, and the annual cost is higher as a result. The thermostat settings were also critical. The exterior color of the house and the material and color of the roof were also significant. The houses we studied were older, standard building stock, with dark-shingle, red-tile, or standard built-up roofs. These last either were uncoated or had a white or aluminum coating. We found that the houses with the darker roofs had significantly greater cooling loads. Finally, we found that the presence of porches decreased the cooling load.

What to Make of the Results?

Our study showed that the physical characteristics of the house, combined with the living habits of the occupants—in particular, how they set their thermostats—far outweighed the impact of vegetation on energy savings. While the computer simulation studies predict ideal average summer energy savings of 7%-8% from the planting of trees, we found that in our actual homes, other real-world effects, such as thermostat settings, obscured any measurable effect of vegetation. The analysis of houses included in this study—existing homes with typical landscaping patterns—was unable to document any measurable savings that were attributable to any of the vegetation variables employed, whether trees, shrubs, grass, or natural desert. This finding indicates that neither shading benefits nor evapotranspiration benefits were realized. The results did, however, confirm the negative impact of trees on the winter heating load that had been documented in previous studies.

We believed that the models might have over predicted the vegetation-induced summer energy savings. The complete lack of demonstrable summer energy savings was unexpected, however. There are two possible explanations for the difference between this finding and the findings of the computer simulation studies. First, it appears that actual landscaping patterns do not correspond to the landscaping configurations used in the simulation studies. In our study sample, the highest average percentage of vegetation was only 39%, for trees on the western exposure. The southern, and more critical, exposure had an average percentage of only 36% for trees. Typical values from simulation studies are 60% or more shading on the southern exposure.

Second, although we factored windows into our study to some degree, we did not look at windows explicitly. We believe that the relationship between windows and the vegetation creating shade is an important factor. Our study showed that thermostat settings are the primary determinant of energy consumption. The thermal comfort of the occupants determines the thermostat setting. If there is significant radiant heat gain through the windows of the home, the thermostat is likely to be adjusted. Shading in this instance would be beneficial, and would probably result in the expected energy savings. Future studies should consider this relationship.

Design Guidelines for Arid Climates

Based on the results of this study, what could the average homeowner in a hot-dry climate do to decrease the annual energy consumption for space conditioning?

The size of the house is one of the most important factors in energy consumption. For every 100 ft^2 added to the house, the winter heating load increases by almost 4% and the summer cooling load increases by almost 3%. Homeowners should carefully consider the size factor when selecting a house, and when adding space to an existing house.

Thermostat settings are important. Setting the thermostat just 1°F lower during the day in the winter decreases the heating load by 2%. Setting the thermostat 1°F higher at night in the summer decreases the cooling load by almost 3%.

Light-colored roofs save energy. Houses with dark roofs in our study consumed almost twice as much energy for cooling as houses with lighter roofs.

Use evaporative cooling whenever possible. Houses with air conditioning consumed an average of 55% more energy than houses with evaporative coolers.

Adjust your thermostat so that your air conditioner or evaporative cooler is off when you are not home. Occupants who did this saved 35% on their cooling energy use.

New houses use less energy for space conditioning. However, although new houses use less energy per ft^2, they also tend to be bigger. One of the real benefits of vegetation in the Tucson environment is that the shading and evapostranspiration make it possible to spend much of the year outdoors. If we take advantage of good landscaping and design comfortable outdoor living spaces, we won't need to build such large houses.

Exterior color was significantly correlated to summer energy consumption. Light-colored houses used 25% less energy than dark-colored houses. (Part of this saving may be due to construction type, since many of the dark-colored houses in the study were masonry.)

Trees should be planted so that they shade the windows. If possible, plant trees that will grow tall enough to shade the roof as well.

Trees and shrubs should be planted far enough away from the house that they don't block the summer breezes, or trap the summer heat against the exterior walls of the house.

Trees planted on the east, west, and particularly south sides of the house should be deciduous species. In desert climates, like that of Arizona, the native vegetation is not completely deciduous. However, there are many new desert-adapted trees and shrubs that are truly deciduous, and these can be used for landscaping in desert climates.

Susan Schaefer Kliman is principal of Klimatic Architectural Design, LLC, in Tucson, Arizona. Her firm specializes in energy-efficient and sustainable design. This article represents a portion of her dissertation research.

Andrew C. Comrie is an associate professor of geography and regional development at the University of Arizona, with joint appointments in the interdisciplinary programs of Arid Lands Resource Sciences, Global Change, and Remote Sensing and Spatial Analysis. He is a climatologist specializing in the geographic aspects of atmospheric environmental issues.

This study was partially funded by the Tucson Electric Power Company and Southwest Gas Corporation.

For more information:

Susan Schaefer Kliman
Klimatic Architectural Design, LLC
Tel: (520)529-1878
E-mail: skliman@klimatic.com

Andrew C. Comrie
University of Arizona
Tel: (520)621-1585
E-mail: Comrie@climate.geog.arizona.edu

This article is a significantly condensed version of a 179-page document, and space constraints prevented the inclusion of much of the statistical discussion. Readers who are interested in more detailed information are welcome to contact us.