MEASURED COOLING SAVINGS FROM VEGETATIVE LANDSCAPING

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The placing of trees and shrubs around buildings has long been recognized as an important technique for reducing heat gain into a building and air conditioning use. Properly selected and positioned vegetation cuts solar gain, shields the building from warm infiltrating air, cools by evaporation, and modifies the microclimate around the building. This paper reviews measurements of air conditioning savings from vegetative landscaping. Only seven projects with energy data and three more with surface temperature data were identified. The experiments took place in humid, dry, and temperate climates. The landscape treatments varied from surrounding the building with grass to complex combinations of trees and shrubs. These studies suggest that plants can cut cooling loads or air conditioning use by 25 - 80%. Wall and roof surface temperatures were typically reduced by 20°C by the vegetation. Several radically different treatments achieved high savings, suggesting that different heat gain mechanisms took place. The shading effects of vegetation appeared to be only partly responsible; indeed, 25% savings were achieved with no change in shading.

INTRODUCTION

Planting trees, shrubs, and ivy around buildings is a familiar strategy to limit solar gain and to create a comfortable environment within a building (Olgyay 1963). If the building is air conditioned, then vegetation will also provide economic benefits. Since many electric utilities in warmer regions experience their peak demand on summer afternoons as a result of widespread air conditioner operation, a reduction in air conditioner electricity demand can avoid construction of expensive power generation capacity.

The value of plantings as a technique to reduce air conditioning loads has not been well documented nor incorporated into analytical procedures. Building standards and design tools generally assume that buildings are built on treeless and exposed surfaces. Architects and engineers will thus favor technologically complex solutions over simpler, cheaper, designs based on the use of trees and other plants. Partly as a result of this information gap, the energy and comfort benefits of vegetation have not fully exploited.

This paper reviews research measuring the cooling savings from the judicious use and siting of vegetation. The major pathways by which plants can reduce heat gain are described, along with attempts to simulate these processes. Several case studies are then summarized. A compilation of surface temperature reductions and energy savings are presented in addition to recommendations for further research.

HEAT GAIN PATHS INFLUENCED BY VEGETATIVE LANDSCAPING

Trees, shrubs, and vines affect air conditioning electricity use in five physically different paths. These paths are: direct gain through windows, conduction gain through opaque surfaces, latent heat from infiltrating air, sensible heat from infiltrating air, and air conditioning system performance.

The relative importance of these paths depends on the vegetation being used, the climate, the building structure, orientation, and type of air conditioning system. Shading of direct solar gain is typically considered the factor most influenced by trees and shrubs, and has therefore received the most attention. In humid locations, however, infiltrating air can be responsible for as much as 50% of the peak cooling load (Roseme et al. 1979; Steen 1976). Thus, the impact of vegetative landscaping on infiltration is also a major consideration. Proper shading of the air conditioner unit, especially the exterior condenser, can also lower energy use. This feature has been poorly researched; however, Parker (1983) claims that shading and evaporative cooling of the air surrounding the condenser lowers supply air by about 4° C. (This improves the unit's COP by as much as 10%.)

Widespread plantings may ameliorate the urban heat island phenomenon; this could reduce air conditioning loads of nearby buildings even though no specific landscape treatments have been applied (Akbari 1990). The impact of heat islands will not be reviewed in this paper.

SIMULATIONS TO ESTIMATE COOLING SAVINGS

The role by which vegetation reduces air conditioning energy use is extremely complex and therefore difficult to accurately predict. In general, current computer simulations appear to be most accurate in modeling the impact of shading by trees (assuming that accurate transmissivities are available), but are less accurate for wind shielding. The simulations are not yet capable of modeling evapotranspiration. One of the major drawbacks is the absence of field data from which to develop algorithms.

With regard to the optical properties, the simplest procedure is to treat the vegetation like a screen with limited transmittance. This corresponds to a kind of shading coefficient. Nayak et al. (1982) used this assumption to compare the relative performance of different shading strategies. They found that a vine-covered pergola (or trellis), combined with a rooftop water film, was the most effective means of reducing heat gain through the roof in a North Indian climate.

In a more sophisticated approach, McPherson et al. (1988) simulated the energy savings from tree shade using the MICROPAS hourly simulation model. Assumptions were made on the percent reduction in solar gain and infiltration that would be derived from various types and locations of plantings. These were used to predict energy and dollars saved for four U.S. cities.

Holm (1989) adapted the DEROB hourly building simulation program to model the thermal effects of deciduous and evergreen vegetation on an external wall. The modifications included an outer surface with an absorptance spectrum similar to total leaf cover, multiple air spaces, ventilation, thermal mass, and thermal resistances. The physical values were calibrated through measurements of actual vegetation. The reduction in inside temperature due to a leaf cover on the external walls was then calculated. Air conditioning savings due to reduced heat gain could be calculated using this information. This model did not attempt to include the energy flows caused by plant transpiration.

Huang et al. (1990) sought to simulate the impact of trees on heating and cooling energy. These simulations adjusted for the direct light transmissivities of the trees, and the diminished infiltration due to the plant windbreaks. The simulation model (DOE-2.1D) treated the shading effects of the trees as exterior building shades, whose transmissivities were determined by earlier work. The model included the impact of reduced diffuse light by adjusting the sky- and ground-form factors. DOE-2 does not have the means to calculate the savings from evapotranspiration, although the authors concluded from an earlier investigation (Huang et al. 1978) that its impact was greater than that from wind shielding or shading. The model could not include the tree-caused changes in longwave radiation, but the authors believed this to be a small effect.

Detailed vegetation models exist (Terjung and O'Rourke 1980; Halverson et al. 1980) but they are poorly linked to the building energy models. As a result, even the most sophisticated models cannot completely simulate some of the key processes associated with heat gains affected by vegetation (Huang et al. 1990; Holm 1989). Several phenomena resist easy simulation. Among them is the heterogeneous optical characteristics of the plants. These shortwave characteristics include the fractions of light that penetrate, reflect, or are absorbed by the plant. This affects direct gain and sol-air calculations. A second problem is modeling longwave radiation energy exchanges between the building's surfaces and the surrounding surfaces (including nearby buildings).

A third problem is modeling the microclimate established in the area between the building surfaces and adjoining plants. The shading caused by the vegetation, moisture released through evapotranspiration, and closer thermal linkages to the ground, modifies the microclimate surrounding parts of the building. It lowers temperatures and increases humidity. The microclimate may lower building surface temperatures, induce convection currents, and protect building thermal mass.

A fourth problem is predicting the infiltration reductions caused by wind-shielding. Plants can be used create a barrier to wind, and therefore reduce air pressure differences on the building surfaces. Specific effects are determined by site configuration and the wind speed and direction.

The dynamic and heterogeneous phenomenon of vegetative landscaping are challenging, but not impossible, to simulate. No doubt simplifying models could address specific situations. However, the chief obstacle remains the lack of measured data on which to validate algorithms and assumptions.

CASE STUDIES

Few studies exist where air conditioning energy savings caused by vegetative landscaping have been directly measured. Such experiments are difficult because plants take many years to grow, and few researchers can wait so long for the desired environmental conditions to develop. This dilemma has been circumvented through a number of strategies. First, researchers have created temporary environments that closely resemble a building surrounded by planted landscape. These temporary landscapes consist of fully-grown plants moved to the site. Second, researchers have focused on plants that grow quickly, such as vines. Finally, researchers are attempting to locate serendipitous comparison groups. For example, the energy use of buildings with extensive plantings might be compared to a similar group without plants. Six studies are summarized below.

Parker (Parker 1981; Parker 1983; Meier 1987) investigated the cooling savings due to vegetative landscaping around a double-wide mobile home (used as a nursery school) in Miami, Florida. The hot/humid climate and high internal loads required air conditioning for over half of the year. The building was originally situated on a clear site. Parker planted a multi-layer canopy of fully-grown shrubs and small trees (2 - 8 m high) around the building. These plants were intended to shade windows and walls, create a cooler microclimate adjoining the walls, and shield the building from warm, afternoon breezes. Parker compared air conditioner energy use before and after the trees and shrubs were planted for two days with similar conditions. Measured air conditioning savings exceeded 50% for comparable hot days, but long-term savings were about 25%. The savings would have been higher but the occupants selected a lower inside temperature after the trees were planted. In addition, the air conditioner was undersized; some of the potential energy savings were converted into lower indoor temperatures during the warmest periods.

Hoyano (1988) conducted a series of experiments to measure the cooling effects of vines and trees. These experiments mostly took place near Tokyo, Japan, whose summer climate is hot and humid. In one experiment, Hoyano placed a trellis planted with vines over a veranda. A neighboring, identical unit served as the control. In a second experiment, vines were grown over a west-facing wall of a residence. During the summer, the heat flows were compared on units with vines and without. Hoyano also tested the impact of trees placed in front of a west-facing wall. The trees were kept in containers so that the distances between trees and between the trees and the wall could be varied. Even for widely-spaced trees, the heat gain through the wall was cut by over 50%.

McPherson et al. (1989) constructed 1/4-scale model homes and measured their cooling energy consumption with different landscapes. This experiment took place in Arizona, a desert climate where water is expensive. Therefore a major goal was to find a landscape that reduced cooling energy but did not require a lot of water. One building served as a control; its "yard" consisted of a layer of decomposed granite, about 5 cm deep. Two landscape treatments were compared: a traditional turf lawn and a selection of low-water use shrubs. The turf landscape cut air conditioning energy use by about 25% even though it did not affect shade on the structure.

Slightly greater savings were achieved through the judicious placement of shrubs around the building (leaving the remaining ground covered with decomposed granite). The physical process in which the two landscapes saved energy appeared to differ. The shrubs cut cooling energy by direct shading and modifying the microclimate around the building (less than a few meters wide). The turf cut cooling loads through extensive evaporative cooling which decreased air temperatures over the whole yard and around the house. (The turf also used about 10 times more water than the shrubs.) The turf probably reduced also longwave radiation gains and increased reflection.

The use of scale models introduces some uncertainty because physical processes scale differently (Meier 1989). The results from models may overstate the importance of effects that depend on the building's surface area.

Parker (1990) investigated the impact of vegetation around 25 air conditioned houses in Florida and rated them on a scale from 0 (no shading) to 3 (heavily shaded in all directions). He then inferred the impact of plants by regressing total energy use against level (0 to 3) of landscape and several other variables. The variables explained about 75% of the variation in total energy use. The shading class was a statistically significant determinant of air conditioning use. Houses with moderate or heavy shading (shading class 2 or 3) used about 34% less air conditioning energy than houses with no shading (class 0). This corresponded to roughly 15 kWh/m^2-yr or 3300 kWh/yr for the average house in the study.

The greatest electricity savings--80%--were reported by DeWalle et al. (1983). This project consisted of moving small, air conditioned trailers between a forested and open site. The experiment took place in Central Pennsylvania, whose summer is not particularly harsh, and the initial average power use of the air conditioner was only about 300 Watts. As a result, the air conditioning loads are susceptible to almost complete elimination once solar gains are blocked. Nevertheless, the experiment demonstrates that even forest vegetation can greatly reduce air conditioning energy use.

The largest reduction in heat gain was reported by Harazono et al. (1989). Half of a roof was covered with vegetation (in trays grown with hydroponics). Essentially all of the heat gain into the top floor of the building was eliminated (and, at times, the direction of heat gain was reversed).

MEASURED TEMPERATURE REDUCTIONS

A direct consequence of strategically placed vegetation will be lower temperatures on the building surfaces. The temperature reduction of the building surface is only one facet of the landscape's interaction with building air conditioning use. For example, the temperature drop does not indicate the extent to which infiltration is affected, and only partially reflects microclimate changes. Nevertheless, exterior surface temperature data are useful for calibrating simulation models and predicting energy savings in other conditions or locations. Surface temperatures can be used to calculate crude thermal resistances of the vegetation barrier.

Several researchers have measured exterior surface temperature reductions due to vegetative landscaping. These temperature reductions are presented in Figure 1, and some experimental details are listed in Table 1. All of the experiments reported considerably more information than is presented in the Table, so the results for similar conditions are

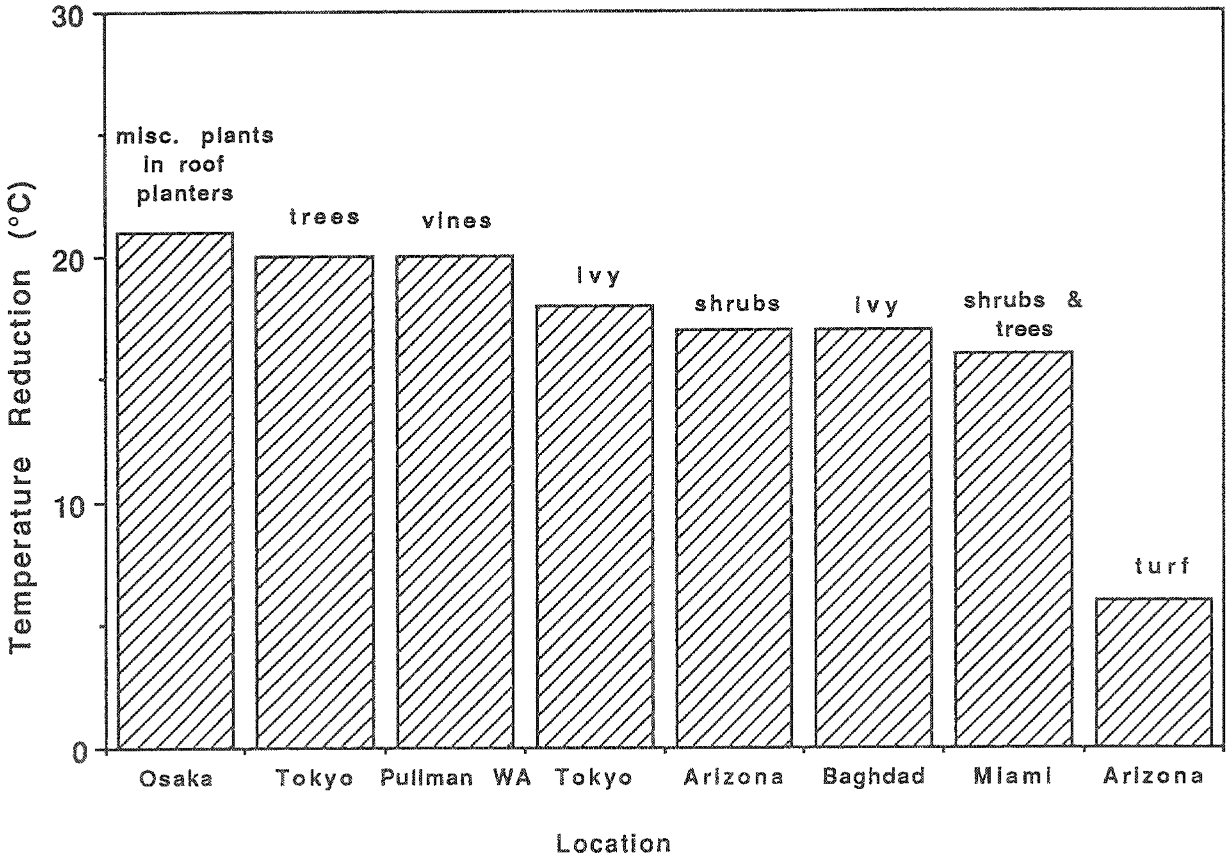

Figure 1. Surface Temperature Reductions Due to Vegetation. Most were measured on west-facing walls, with and without vegetation. The principal form of planting is listed above the result. The reductions are peak values, and generally occurred around 3 PM.

generally listed, that is, a west wall at about 3 PM. This is usually the time at which maximum temperature reductions were found. (The exception is the case of rooftop vegetation, whose maximum solar load occurs around mid-day.)

The results must be interpreted with caution because each researcher used somewhat different experimental set-ups and procedures. For example, each measured west wall temperature differently. It is probably coincidental that the vegetation consistently lowered the wall surface temperature by about 17° C, but the reduction is significant in all cases. The temperature reduction occurred with several types of vegetation, from thick ivy to strategically placed shrubs and trees. Moreover, the reduction occurred in both hot/dry climates (such as Iraq) and in hot/humid climates (such as in Florida). Surrounding the house with turf (McPherson 1989) caused only a 6° C wall temperature drop. This is not surprising because the turf added no shading. This result suggests that the creation of a more humid microclimate around a building can alone reduce wall temperatures. This effect has not yet been incorporated into building simulations.

MEASUREMENTS OF ENERGY SAVINGS

Measured energy savings from vegetative landscaping are difficult to standardize because researchers used diverse methods and measured different kinds of savings. Results are given in Table 2 summarized in Figures 2 and 3. Some

Table 1. Surface Temperature Reductions from Vegetative Landscaping

Author & Year	Location & Climate	Type of Planting	Wall-Veg. Distance	Difference Measured	ΔT	Notes
J. Parker 1981	Miami, FL hot/humid	shrubs and trees	shrubs < 1m trees < 10m	wall with & without plants	16°C	west wall, 5 PM, maximu value; about 1 month ap
Hoyano 1988	Tokyo Japan hot/humid	ivy covering	touching	wall with & without ivy	18°C	west wall, 3 PM, maximu value; 1 year apart
Hoyano 1988	Tokyo Japan hot/humid	dense canopy evergreens (Kaizuka hort)	0.2 - 0.6m	wall and inside plant surface	5 - 20°C	west wall, 3 PM parallel measurements
McPherson 1989	Tucson, Ariz. hot/dry, desert	18 shrubs and 5cm decomposed granite	0.5 m	wall with shrubs & no shrubs	17°C	west wall, 3 PM different buildings
McPherson 1989	Tucson, Ariz. hot/dry, desert	turf, extending about 5m from structure	surrounding building	wall with turf vs. decomposed granite	6°C	west wall, 3 PM different buildings
Makzoumi & Jaff, 1987	Baghdad, Iraq hot/dry desert	vine (luffa cylindrica) on trellis	0.1 - 0.4 m	wall with & without vines	17°C	southwest wall, 3 PM, m value, different buildings
Harazono 1989	Osaka, Japan hot/humid	rooftop hydroponic using lightweight planting substrates and mixed plants	0.1m	half of roof with half without	21°C	average for 10AM-6PM on clear August day
Halvorson 1984	Pullman, WA temperate	vertical vine canpopy	n.a.	wall with and without vine	20°C	

Table 2. Energy Savings from Vegetative Landscaping

Author & Year	Location & Climate	Type of Planting	Energy Measurement	ΔE (Watts)	ΔE (%)	Notes
Air Conditioning						
DeWalle et al 1983	Cent. Penna. temperate	forest site vs. clear site	AC electricity for identical mobile homes	230	80%	37-day test period
J. Parker 1983	Miami hot/humid	FL shrubs & trees	AC electricity with & without landscaping	5000	58% 24%	6-hr (afternoon) test period 10 day periods
McPherson et al 1989	Tucson AZ hot/dry desert	shrubs surrounding model house	AC electricity with & without shrubs	104	27%	2 week period
McPherson et al 1989	Tucson AZ hot/dry desert	turf surrounding model house	AC electricity with & without turf	100	25%	2 week period
D. Parker 1990	Palm Beach FL hot/humid	misc. trees and shrubs	annual elctricity for whole house	1.8 W/m^2	34%	inferred from regression of 25 houses, from landscape class 0-->2,3
Heat Gain						
Hoyano 1988	Tokyo Japan hot/humid	vine covered wall	heat gain with and without vines	175 /m^2	75%	peak value at 4 PM on west wall
Hoyano 1988	Tokyo Japan hot/humid	row of evergreens next to wall	heat gain through wall	>60 /m^2	>50%	peak value at 4 PM on west wall for widely spaced trees
Harazono 1989	Osaka, Japan hot/humid	rooftop vegetation	half of roof with, other half without	130/m^2	90%	average from 10AM-4P

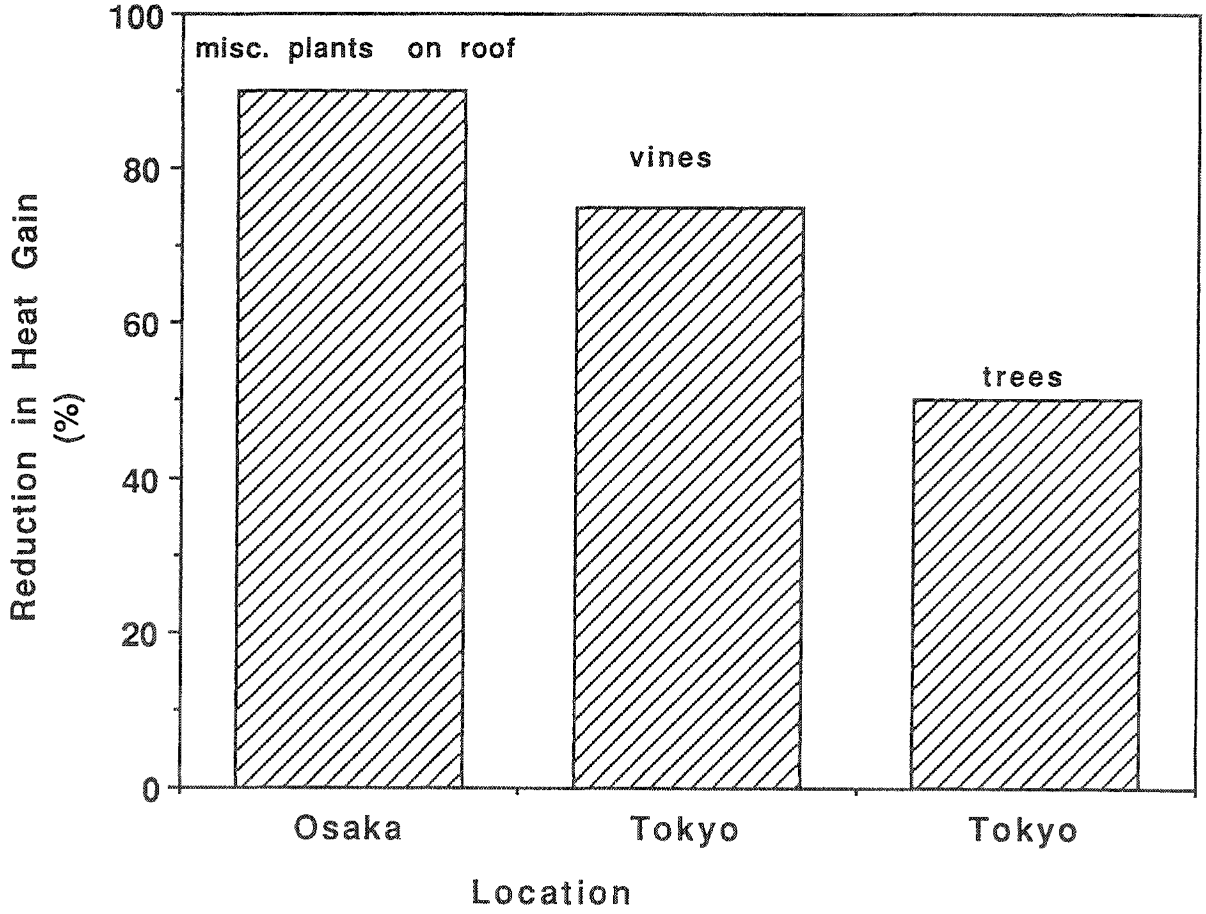

Figure 2. Reduction in Heat Gain Due to Vegetation at Various Locations. The principal form of vegetation treatment is listed above the result.

researchers measured the reduction in heat gain through a wall (Figure 2), while others measured the air conditioning energy required to maintain a pre-set indoor temperature (Figure 3). The period of monitoring likewise varied. Heat gain is typically measured for a few hours, while monitoring air conditioning energy use might be monitored for several weeks. Measurements of heat gain were generally made on a wall section or test cell, while air conditioning electricity use was measured in whole structures. For these reasons, both the absolute and fraction of energy saved (expressed in terms of average power, Watts) are listed.

Measured air conditioning savings from vegetative landscaping ranged from 25 - 80%. The variation in absolute savings was much greater, but this simply reflects the range in experimental conditions, that is, from a small trailer in a temperate climate to a double-wide mobile home in a hot, humid climate.

The measurements by McPherson et al. (1989) demonstrate the complexity of the relationship between the landscape and air conditioning loads. Roughly 25% savings were achieved by two different physical processes. In one case, the savings were obtained by careful selection and siting of shrubs around the structure. The principal causes were probably direct shading, the modification of a narrow, cooler, microclimate surrounding the structure, and limited evaporative cooling. When the yard was covered with turf, the savings appeared to be due to the turf re-radiating less longwave energy, and creating a larger evaporatively-cooled microclimate around the house.

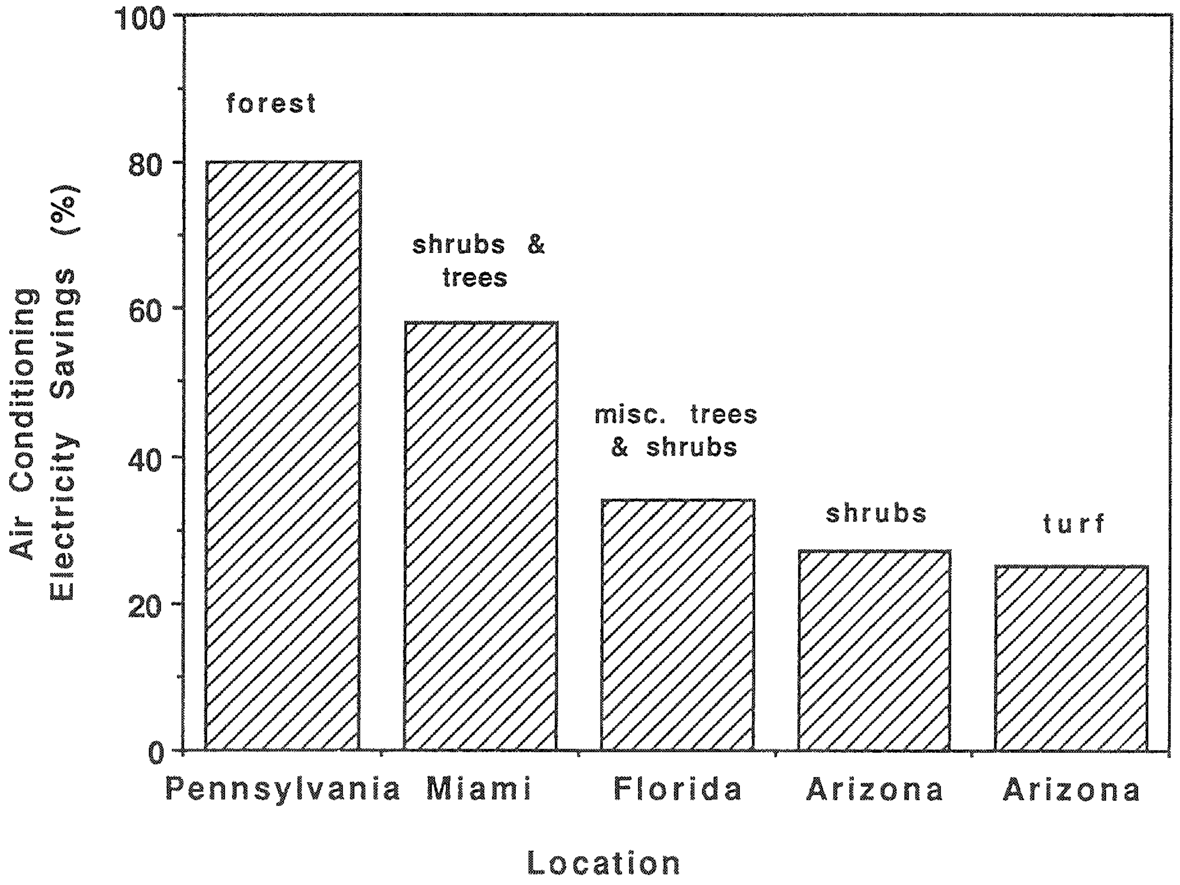

Figure 3. Air Conditioning Electricity Savings Due to Vegetation at Various Locations. The principal form of vegetation treatment is listed above the result.

Parker's (1981) and McPherson's (1989) results also indicate that vegetative landscaping affects more than just solar gains. This is shown by the extent to which energy is saved before the sun was even shining on the building. Moreover, this phenomenon was observed in two dramatically different climates.

CONCLUSIONS

Only a few attempts have been made to measure the air conditioning savings due to plantings. However, consistently large savings were achieved. This suggests that the careful application of shrubs, trees, and vines could reduce cooling electricity use 25-50%.

These savings were achieved in a variety of climates and using greatly different landscape treatments. Reductions in air conditioning energy were obtained even in humid climates. Large savings were also obtained in a dry climate simply by planting grass around the building. These results suggest that vegetation interacts with heat gain through many physically different processes, and that several combinations of vegetation and siting may yield similar savings.

In spite of the impressive savings achieved, the studies reported here are generally poorly documented and use widely differing measurement techniques. It is difficult to confidently apply these results to simulation models or other situations. Further research is needed to create a broader base of measurements. This research should include analysis of more buildings, different combinations of plantings, and careful monitoring of the temperature and energy use. The most valuable type of experiment appears to be cases where the same building can be compared with and without vegetative landscaping. In addition, special attention should be directed towards any maintenance problems resulting from the use of intensive planting around the structure.

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