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Green Roofs in the Tropics Conserve Energy

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Abstract: *Background:* Concrete buildings on Guam are exceptionally strong but also accumulate large amounts of heat. In the tropical environment of Guam, where 24 h average temperature ranges from 28 to 29ºC year round, air conditioning is used every day and continuously. Concrete roofs are often painted light colors, which make them more reflective and accumulate less heat. They are also suitable for establishment of vegetation, which results in a large decrease in roof temperature and therefore decreases the need for cooling.

Objective: The objective was to determine the magnitude of temperature reductions resulting from light color and from vegetation covering roof tops and to use this information to estimate energy savings.

Method: Temperature was measured on the undersides of concrete model roofs in both sunny and rainy weather.

Results. The temperatures on the undersides of light-colored concrete model roofs rose up to 3ºC less in the course of the day than did those of dark-colored ones. The temperatures of "green" (vegetation-covered) model roofs rose up to 12ºC less than did those of either of the bare concrete models.

Conclusion: The differences were so large that use of green roofs on the tropical island of Guam, where most buildings are concrete and air-conditioning is needed year round, could cut a typical household's electric consumption in half.

Keywords: Green roof, energy conservation, roof vegetation.

INTRODUCTION

Roof tops are usually unattractive places where heating and cooling equipment, telecommunication towers, and satellite dishes are installed [1]. Several decades ago in Europe, and then in other countries, ecologists, anthropologists, sociologists, and environmentalists stressed the need for more harmony between lifeless city buildings and their occupants [2]. As a result, thousand of hectares of roof-top area in large cities around the world were converted into gardens, as places of recreation or simply esthetically pleasing components of city skylines [3]. These "green roofs" also provide many functional benefits. The most important are energy conservation [4 - 8], cooling effects [9, 10], reduction of city noise [11, 12], mitigation of air pollution [13 - 15], delayed storm-water runoff, and improvement of runoff quality [16 - 18].

Guam, a tropical island in the western Pacific populated by almost 180 thousand people [19], serves as major year-round destination for 1.5 million Asian tourists annually [20]. Because of frequent typhoons and occasional earthquakes since the 1950s, nearly all walls and roofs of residential and commercial buildings are constructed from solid concrete. Concrete buildings are exceptionally strong and safe but also accumulate large amount of heat. The heat is currently removed by air-conditioning units (AC), but the need for AC could be reduced if roofs were shielded from hot sun. Because concrete structures assure exceptional weight safety, roofs on Guam are suitable for establishment of vegetation. Abundant tropical rainfall and selection of appropriate plant species could eliminate or greatly reduce the need for irrigation, making roof vegetation relatively easy to grow and maintain.

The objective of this study was to determine the magnitude of temperature reductions resulting from vegetation covering roof tops and to use this information to estimate the impact of roof-top vegetation on the amount of energy

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needed to cool a typical residential house on Guam.

MATERIALS AND METHODS

This study was conducted on Guam (13°N latitude). Eight 3.1m by 0.9m concrete plates were placed on concrete blocks 0.4m above the ground. The plates were 0.13m thick, were reinforced with steel bars, and resembled those used for an ordinary residential roof (Fig. **2**). Each plate was divided into two 1.5m by 0.9m plots. Steel wire mesh was affixed to the surface of each plate, and a 10cm layer of turf substrate (Scotts Lawn Supersoil®) mixed with sand was spread over four plates on eight of the plots. The other eight plots were left without soil substrate. Four soilless plots were similar in color to a well-maintained concrete surface, and the other four were darkened to resembled a poorly maintained (and unfortunately quite typical) concrete surface covered by black fungi and algae.

Zoysia tenuifolia turf was established on four soil-covered plots from plugs, and full coverage was achieved within a year ("turf roof"). A mixture of indigenous weeds (monocots and dicots) was permitted to establish itself on the remaining four soil-covered plots and established full coverage within several months ("weed roof"). Turf was not mowed or fertilized after establishment but was lightly top-dressed with sand after a year. Weeds thrived and were trimmed occasionally. Turf roofs and weed roofs were irrigated only occasionally and during sunny periods suffered frequent water stress. Before data collection began, turf and weeds were thriving but were not irrigated. Data were collected during four 3-day periods. Two of the periods, January 19-21 and April 1-3, were without precipitation (sunny). The other two, Mar. 20-22 and September 27-29, encompassed multiple heavy rain events and substantial water runoff (rainy).

During sunny and rainy periods, average minimum air temperature ranged from 24 to 26°C and maximum temperature from 30 to 32°C. Day length ranged from 11.5 h in January to approximately 12 h in the remaining three periods. Average humidity for the sunny periods was 75% and for the rainy periods was around 90%.

Temperature was measured on each plate’s bottom surface in five locations per plot with an infrared thermometer (Ryobi, Model E49IR01), and the resulting readings averaged. Temperature readings began around sunrise and were repeated every 3 h until sunset. Accuracy of infrared thermometer readings was evaluated by comparison to a direct method of 20 random readings taken with Traceable® probe. The differences were less than 0.5°C.

All data were analyzed with SAS 9.1.3 software (SAS Institute Inc., Cary, NC). Experimental design was an unbalanced split-plot design with repeated measures. The SAS-MIXED procedure was used to produce a table of Type III tests of fixed effects. Means were separated by means of Fisher’s LSD procedure at $P < 0.05$.

RESULTS

Temperature differences between bare concrete plates and these covered by vegetation were significant by 3 h after sunrise and reached a maximum within 9 h. On sunny days, plates covered by vegetation were up to 12°C cooler, and on rainy days about 9°C cooler, than bare concrete plates (Fig. **1**). Temperature fluctuations in concrete under vegetation were small on both sunny and rainy days. On sunny days, light-colored concrete was about 3°C cooler than dark-colored concrete; on rainy days, temperature differences were smaller. Temperature of plates covered by turf was similar to that of roof covered by weeds. During sunny days, plates under vegetation cooled down more slowly than did bare concrete and remained at least 2°C warmer at the next sunrise. During rainy days, all plates reached the same temperature by the next sunrise.

DISCUSSION

In tropical locations, sunlight falls more nearly vertically than in other regions, so the roofs of buildings receive most of the solar energy. Because most residential houses on Guam are all concrete and without attics, the underside of the roof radiates heat directly into the living area. Powerful AC is therefore needed to offset heat generated by the roof inside the house. In the tropical environment of Guam, where 24 h average temperature ranges from 28 to 29°C year round, AC is used every day and continuously.

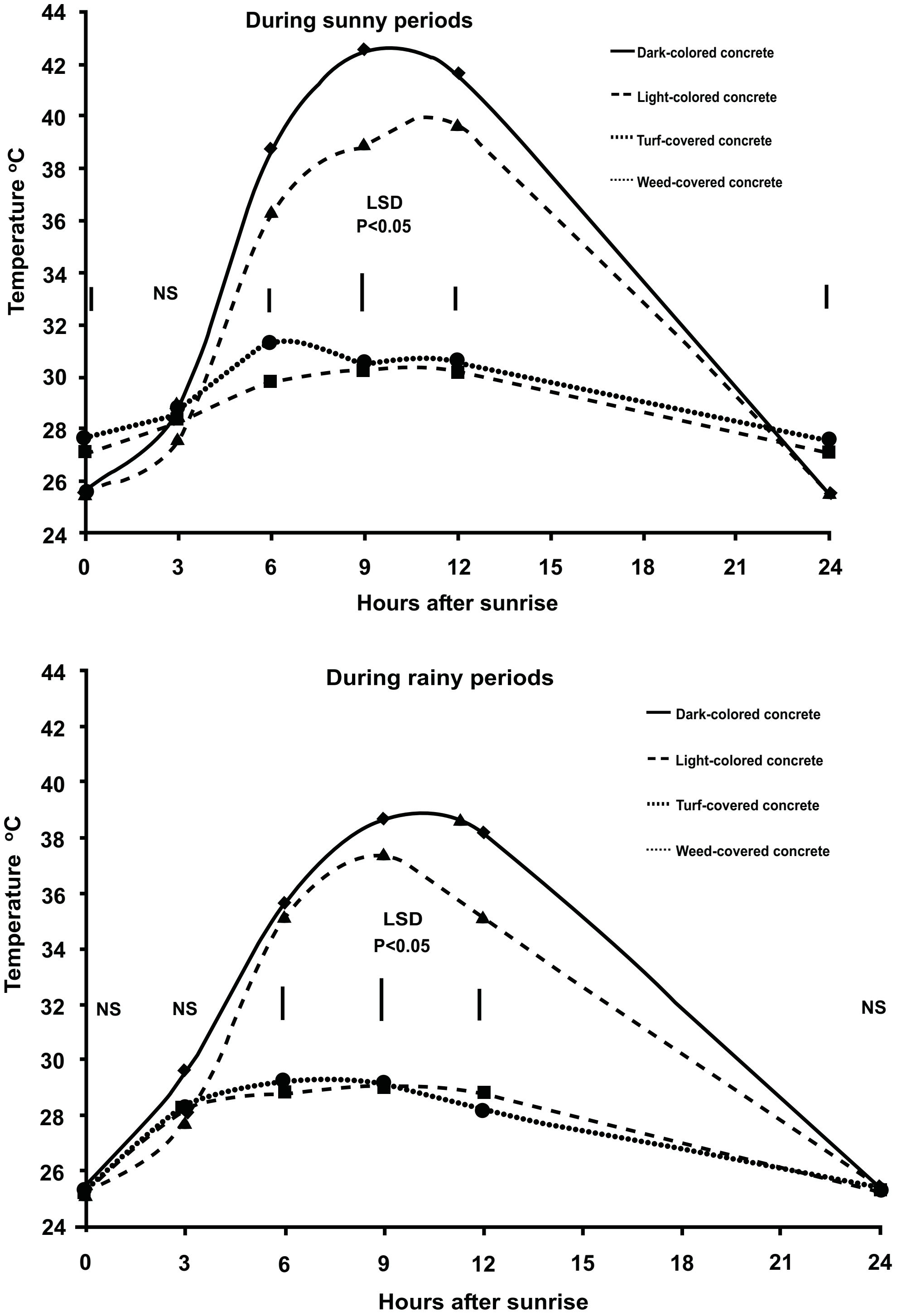

Fig. (1). Temperature of model concrete roofs, in °C (6-d average.), showing that, in both sunny and rainy weather, the temperatures on the undersides of light-colored concrete model roofs rose less than did those of dark-colored ones and that temperatures of "green" (vegetation-covered) model roofs rose less than did either of the others.

Collected data indicated that maintaining a concrete model roof surface free of algae and light in color resulted in a meaningful decrease in roof temperature and therefore would decrease the need for AC. Installation of vegetation on the model roof increased this desired effect even more. Santamouris [21], in his comprehensive review, evaluated results from numerous studies involving green roofs and reflective roofs and concluded that green roofs are advantageous in conserving energy in cold climates, whereas reflective roofs are better in warm and sunny climates. Results from my experiment indicate just an opposite. The clear advantage of the green roof over the reflective roof on Guam results from the location's uniform year-round hot climate. Most of the studies cited by Santamouris were conducted under conditions where green roofs often served as insulation, retaining the structure's internal heat rather than preventing warming. On Guam, concrete roofs are the warmest part of the house structure, and heat is transmitted always toward the inside of the building. In addition, reflective roofs in extremely humid climates are impractical. The rapid growth of dark algae on the roof surface significantly reduces its reflectance within several months after painting, making them expensive to maintain. In future studies, I plan to conduct similar experiments on structures that more realistically simulate house construction on Guam, for example structures at typical roof height and with side walls in place. Liu [22] reported that roof vegetation reduced energy consumption by 75% during summer months in Ottawa, Canada. Dunnett and Kingsbury [11] reported that every decrease in internal building temperature of 1°C can reduce electricity use by AC up to 16%. Peck *et al*. [7] reported that roof vegetation in southern Canada reduced indoor temperatures by about 4°C when outdoor temperatures were between 25 and 30°C. In this experiment, indoor air temperature was not measured, but observations (not shown) indicate that, during daytime on Guam, heat from a concrete roof can increase indoor temperature by 10°C or more. Using the conservative number of 4°C reported by Peck *et al*. [7] rather than the higher numbers from Guam or Ottawa, calculations recommended by Dunnett and Kingsbury [11] indicate that roof vegetation can reduce AC energy consumption by 64%. On Guam, typical energy consumption by an air-conditioned residential house maintained at 24°C oscillates around 2000 kWh per month [23]. Because the Guam Power Authority estimates that 75% of all such energy is used by AC, a reduction of 64% could cut total energy use in half. Because the price of electricity on Guam is twice the U.S. average [24], the benefit of roof vegetation could be immense.

Fig. (2). Concrete plates used in the experimental structures were 0.13 m thick and resembled those used for ordinary residential roofs. Vegetation was established on half of the plates, and half were left without vegetation.

Temperature data indicated little difference between turf and a mixture of weeds, but zoysia turf is considered more attractive than weeds and, unlike weeds, requires infrequent trimming, every 2-3 years. In addition, the root system of zoysia turf is exceptionally dense, and should therefore attach itself more firmly to roofs and hold soil particles better than weeds. High root density would also make turf more resilient to occasional typhoons accompanied by extremely heavy tropical rainfall.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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Declared none.

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