SIMULATING MICROCLIMATIC EFFECTS ON BUILDING ENERGY USE

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INTRODUCTION

Vegetation can have an important role in the amelioration of meso- and micro-climates of cities. This fact has important implications for municipal water use and electrical energy demand for space cooling, both of which have far reaching implications in terms of water supplies, peak electrical demand, and generation of greenhouse gases. Thus, it is important that both the benefits and the costs of vegetation be considered when evaluating the place of vegetation in the urban environment.

To investigate the effects of vegetation on urban energy and water use, one-quarter scale model houses were situated in three representative landscape treatments (McPherson et al. 1989): (1) Bermuda grass TURF with no shade, (2) rock mulch with SHADE from shrubs (no turf), and (3) ROCK mulch with neither turf nor shade. It was concluded that the ROCK landscape used 20 to 30% more energy for cooling than either TURF or SHADE, the latter two using about equal amounts. These energy savings were large enough to pay irrigation costs for low and moderate water use plants, but not for the water demands of turf.

One surprising result of that study was that the TURF treatment had as large an effect as the SHADE treatment on reducing energy use, indicating that reduction of exterior air, building exterior and surrounding ground surface temperatures by turf was as effective as heavily shading a building's walls from the direct sun in reducing heat gain. Consequently, the objective of this paper is to combine the results of the scale model study with a computer simulation analysis of building cooling load to describe the resulting energy flows and quantify their relative importance in terms of building heat gain. These results will then be used to simulate the heat gain and cooling load for the TURF and ROCK treatments and, hence, gauge the importance of selected environmental effects on energy use.

METHODS

The scale models, landscape treatments, environmental measurements, and other details have been described elsewhere (McPherson et al. 1989). That paper considered data for the year 1987, while the current results are for a similar period in September 18, 1988, a clear, warm day in Tucson, Arizona. The microclimatic factors most important in determining building heat gain are solar and terrestrial radiation, convection, and infiltration. Landscaping influences these via shading, air and surface temperature modification, or changes in wind speed.

Heat gain and cooling load were determined using the transfer function method described in ASHRAE (1985). In this two-step method, transfer functions are used to represent the effect of thermal storage on heat gain. In the first step, heat gain at interior surfaces is computed, while in the second the transfer of this heat to the room air as cooling load is determined. Heat gain components are conduction through walls, roof, doors (opaque conduction) and windows (glazed conduction); solar radiation through windows (glazed solar); infiltration (sensible and latent heat); and internal sources.

Sol-air temperature (T_e) is used to represent outdoor conditions for calculation of opaque conduction. T_e incorporates the effects of both solar and terrestrial radiation into an effective air temperature that allows the heat transfer to the building surface from radiation to be treated as convective transfer. This allows a simplified analysis of the transient heat flow equation. The various energy budget calculations and the transfer function models for heat gain and cooling load were implemented using Lotus 1-2-3 spreadsheets. Energy use comparisons were done in terms of electrical use for air conditioning, which was determined from the measured kW-hrs by subtracting the known power used by other loads, in this case only the lights and air conditioner fan. No other electrical loads were present. Cooling load computed from the simulations was converted to electrical load using the manufacturer's supplied energy efficiency ratio, or EER. The EER's were adjusted from 8 to 15% using on-site calibrations.

RESULTS

Relative Magnitude of Heat Gain Components. The ROCK treatment used about 29% more energy overall for cooling than did TURF as a percentage of the total ROCK energy use (Table 1), which is in substantial agreement with earlier results (McPherson et al. 1989). This excess was split about evenly between opaque conduction, glazed conduction and infiltration, while slightly larger TURF albedo was reflected in about a 1% larger heat gain for TURF (Figure 1). These results were strongly influenced by wall, ground and air temperature differences (Figure 2).

Comparison of Measurements and Simulations. Overall, modeled electrical usage agrees quite well with the measurements (Figure 3). For the 24-hour period, total load is overestimated by 5% for TURF, underestimated by 5% for ROCK. On an hourly basis, modeled load agrees with measured load much of the time (within 5%) for both treatments, the major exception being the period from 0800 to 1100 hours, especially for TURF. The lag in measured TURF energy use compared with predictions is probably due to the fact that in the early morning, the TURF building cools below the air conditioner

Table 1. Electrical Power Used for Air Conditioning

kW-hr ROCK	kW-hr TURF	Difference kW-hr	Difference %	Component
-51	208	258	7	Wall conduction
251	359	109	3	Roof "
-219	160	378	10	Glazed "
1649	1619	-30	-1	Glazed solar
-126	285	411	10	Infiltration
1292	1292	0	0	Internal
2797	3923	1126	29	Total

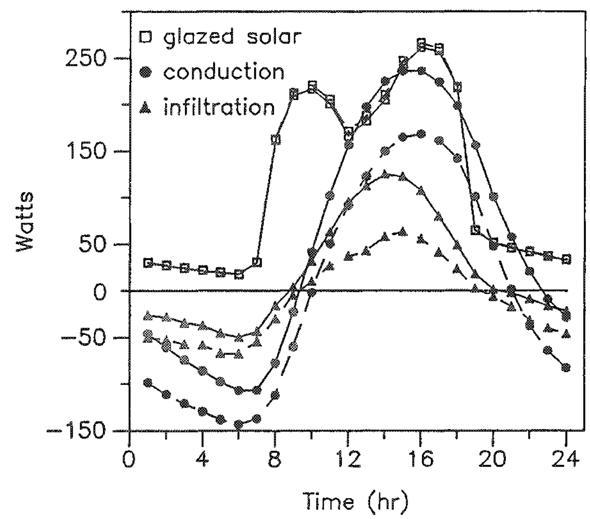

Figure 1. Comparisons of Selected Components of Space Cooling Electrical Use for TURF (dashed) and ROCK (solid lines) Treatments

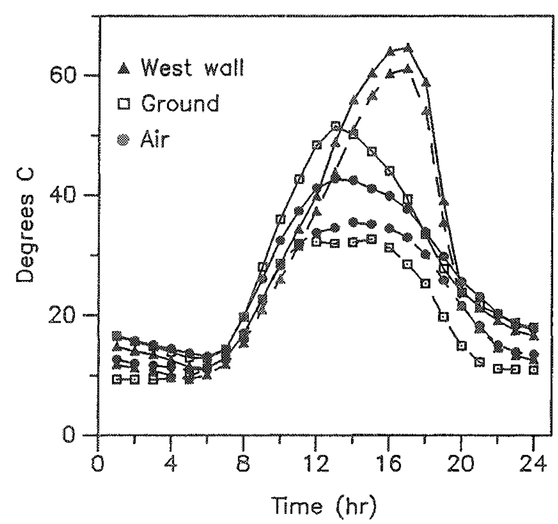

Figure 2. West Wall, Ground and Air Temperatures for TURF (dashed) and ROCK (solid lines) Treatments

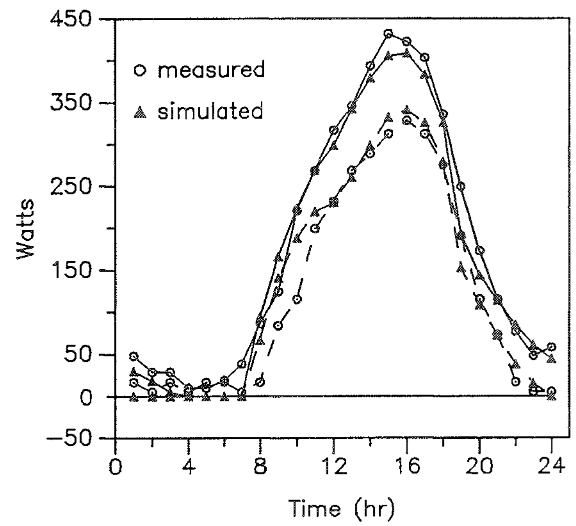

Figure 3. Comparisons of Measured and Simulated Total Electrical Use for Space Cooling for ROCK (solid) and TURF (dashed lines)

set point. Consequently, a lag in measured TURF cooling energy would be expected until the building warmed to above the set point again. The current model assumes a constant inside temperature. The fast rise and then small decline in simulated energy use during these hours compared with the measurements may also be a reflection of the bimodal distribution of solar radiation on the building walls (asevident in glazed solar component, Figure 1), caused largely by the partial shading of the south wall by the roof overhang which diminishes the midday solar gain.

In conclusion, the simulation model explained the differences in electrical use in terms of the observed contrast in microclimatic conditions. Consequently, this methodology seems promising for further use in predicting the effects of microclimate on building energy use for full sized buildings in a range of environments. While the substantial effect of air temperature reduction on cooling load found here is applicable to full-sized buildings, the actual air temperature reduction obtainable from turf is expected to be somewhat less. This is due to the diminishing effects of ground surface conditions, and to the larger effects of contrasting upwind surfaces, on air temperature as height increases. In addition, the smaller surface area to volume ratio of full-sized buildings tends to reduce infiltration effects. Research is currently under way to address these issues.

REFERENCES

ASHRAE Handbook, Fundamentals Volume. 1985. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia.

McPherson, E. G., J. R. Simpson, and M. Livingston. 1989. Effects of three landscape treatments on residential energy and water use in Tucson, Arizona. *Energy and Buildings* 13:127-138.