Reprinted from the preprint volume of the 12th Conference on Biometeorology and Aerobiology, 28 Jan - 2 Feb, 1996, Atlanta, GA. Published by the American Meteorological Society, Boston, MA.

2.10

ESTIMATING URBAN FOREST IMPACTS ON CLIMATE-MEDIATED RESIDENTIAL ENERGY USE

J. R. Simpson* and E. G. McPherson

Western Center for Urban Forest Research and Education
Davis, California

1. INTRODUCTION

Interactions between urban trees and the environment are numerous. Trees can reduce runoff by intercepting precipitation, absorb pollutants and emit hydrocarbons, and modify solar radiation, air temperature, wind speed and relative humidity. Of particular interest in recent years has been the reduction in energy use for building space conditioning possible through microscale/local scale climate modification that results from urban trees and landscaping.

Computer simulations using prototypical building and tree configurations for cities across the U.S. indicate that shade from a single well-placed, mature tree (about 25-ft crown diameter) reduces annual air conditioning use 2 to 8 percent (40-300 kWh) and peak cooling demand 2 to 10 percent (0.15-0.5 kW) (Huang et al. 1987, Huang et al. 1990, Heisler 1991, Akbari and Taha 1992, McPherson and Sacamano 1992, Sand and Huelman 1993, McPherson 1994, Simpson et al. 1994).

Sacramento Shade, a collaborative tree planting program between the Sacramento Municipal Utility District (SMUD) and the Sacramento Tree Foundation, has as its goal the planting of 500,000 shade trees by the year 2000. Over 170,000 of these trees have been planted to date in residential landscapes in order to increase shade on residential buildings and reduce air conditioning demand. In this paper, shade impacts for a large sample of participants in this program are evaluated. In addition, effects of air temperature and wind reduction from increased tree canopy are estimated to place shade effects in context.

2. METHODS

Shade impacts on building space conditioning energy use were simulated for 254 homes and the immediately surrounding trees in Sacramento County, California. Detailed information gathered for each building and surrounding trees is used as model input.

**Corresponding author address:* James R. Simpson, USDA Forest Service, Western Center for Urban Forest Research, c/o Dept. of Environmental Horticulture, University of California, Davis, CA 95616-8587.

2.1 *Shade & Building Space Conditioning Simulations*

Solar gain reduction from shade was calculated using the Shadow Pattern Simulator (SPS) program (McPherson et al. 1985) based on locations and physical characteristics of adjacent trees and buildings. Characteristics for 30-year-old program trees were estimated from limited field sampling and the literature. Existing trees were classified as small, medium or large; it was assumed that existing tree cover was approximately constant due to a balance between mortality and removal of existing trees by their growth and replacement. Adjacent building shade was approximated by arrays of opaque cylinders of 3 ft diameter located so that their edges were coincident with adjacent building perimeters.

Cooling energy (kWh) and capacity (kW) and heating energy (MBtu) were calculated with Micropas 4.01 (Enercomp 1992). Primary model inputs are 1) building energy use characteristics (e.g. conditioned floor area, window area, insulation, etc.), and 2) hourly annual weather data with solar radiation modified based on SPS results. Pre-1978, 1978-83 and post-1983 construction vintages in one and two story configurations were considered.

2.2 *Air Temperature & Wind Speed Effects*

Space conditioning energy use is not only influenced by reduced solar gain due to tree shade, but also from effects of increased canopy cover associated with large-scale tree planting on air temperature and wind speed. Potential effects on space conditioning from the expected increase in overall canopy cover were estimated to place direct shading results in proper context. Magnitude of climate effects were estimated based on 1) predicted increase in tree cover due to program trees, 2) expected climate modifications from tree cover changes reported in the literature and 3) temperature and wind speed effects on space conditioning based on computer simulation.

3. RESULTS AND DISCUSSION

We present results for annual cooling energy (kWh), capacity or peak demand (kW, average from

1-8 p.m. for the peak cooling day of August 7), and annual heating energy (MBtu) for two scenarios: existing shade from trees and adjacent buildings, and existing plus program tree shade. Effects of program trees on energy use were calculated as the difference between the two scenarios. Results are presented for the entire sample, and grouped by building vintage and numbers of program trees, on a per property and per tree basis. Results grouped by vintage or numbers of trees were normalized by dividing by mean conditioned floor area (CFA) for that group and then multiplying by mean CFA for the entire sample. Discussion of potential air temperature and wind speed effects follows.

3.1 *Average Shade Impacts for all Properties*

Average conditioned floor area for the entire sample was 1718 ft^2. There were an average of 2.8 existing trees, 3.1 program trees and 1.4 adjacent buildings per residence. Mean annual energy used for air conditioning was 2164 kWh before and 1693 kWh after addition of mature program trees, for a savings of 471 kWh (22%). This is equivalent to 153 kWh (7.2%) per tree. Peak demand dropped from 3.18 to 2.95 kW with addition of program trees, for a savings of 0.23 kW (7.1%) per property, or 0.075 kW (2.3%) per tree. Although trees were simulated as leafless from December to March, annual heating energy use increased from 41.8 to 44.4 MBtu, or 2.5 MBtu (7.1%) per property, 0.81 MBtu (2.3%) per tree. These results are in reasonable agreement with other estimates for Sacramento (Thayer and Maeda 1985, Huang et al. 1987, Huang et al. 1990, Akbari et al. 1993). Somewhat larger kW savings found in these studies (e.g. 5 to 10% per tree) reflects the 1-hour averaging period used there compared to 8-hour averages used here.

3.2 *Shade Impacts by Vintage.*

There were 73 pre-78, 35 1978-83 and 146 post-83 vintage homes in the sample; of these, 64, 24 and 92 were one story, respectively, and the remainder two story. Average CFA ranged from 1639 and 2095 ft^2 for post-83 one and two story homes to 1451 and 1867 ft^2 for pre-1978 one and two story homes. For the more numerous single-story homes, existing tree numbers increased from 2.6 for post-83 to 3.6 trees per property for pre-78 buildings. Program tree numbers decreased from 3.5 for post-83 to 2.3 trees per property for pre-78 buildings.

Normalized air conditioning energy use with existing shade increased with building age from 1689 to 3507 kWh per property, as did normalized savings

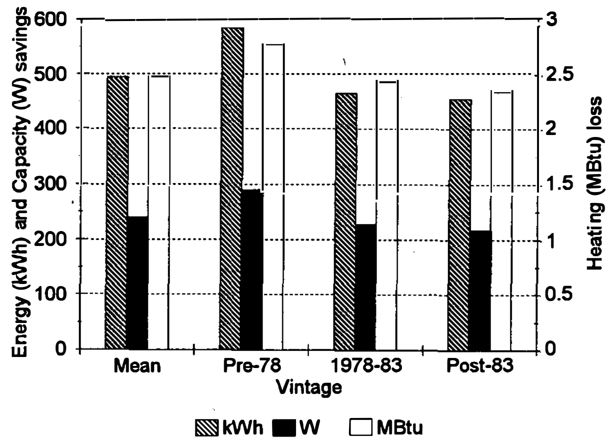

Figure 1. Normalized energy use impacts per property for program trees grouped by vintage.

from 447 kWh (26%) to 572 kWh (16%) per property when program trees were added (Figure 1). Peak demand and savings from shade showed a similar pattern, increasing with building age from 2.4 to 5.0 kW, and 0.21 kW (9%) to 0.29 kW (6%), respectively (Figure 1). Heating energy use and losses from shade increased with building age from 27.7 to 68.5 MBtu, and 2.4 MBtu (9%) to 2.7 MBtu (4%), respectively (Figure 1).

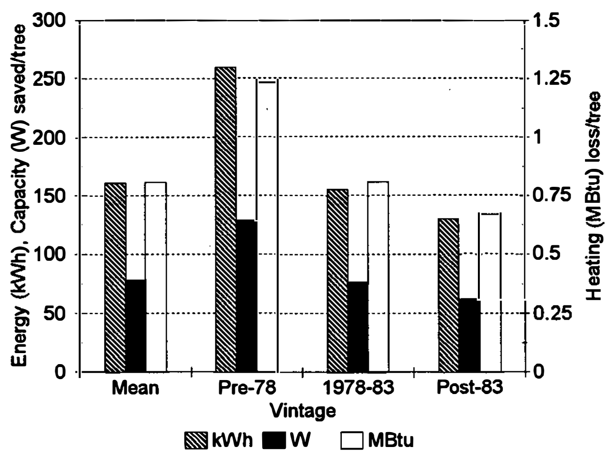

Figure 2. Normalized energy use impacts per program tree grouped by vintage.

Savings differences between old and new construction are greater for data expressed on a per tree basis (Figure 2), since newer properties had more program trees. Cooling savings and heating losses were smallest for newer homes, since their total heating and cooling loads were the smallest.

3.3 *Shade Impacts by Number of Trees*

Numbers of properties with 1, 2 or 3 program trees were similar (61, 62 and 54 properties, respectively); 23 properties had 4 or 5 program trees, and 31 properties had 6 or more trees (16 had 6 trees, 7 had 7 trees, 1 had 8 trees, 4 had 9 trees, and 1 each had 10, 11 and 15 trees, respectively). Normalized annual energy savings (kWh) due to program trees increased from 200 kWh (9%) for one tree to 890 kWh (39%) for 7 trees (Figure 3). Similar patterns were observed for capacity (kW) and heating energy savings (Figure 3).

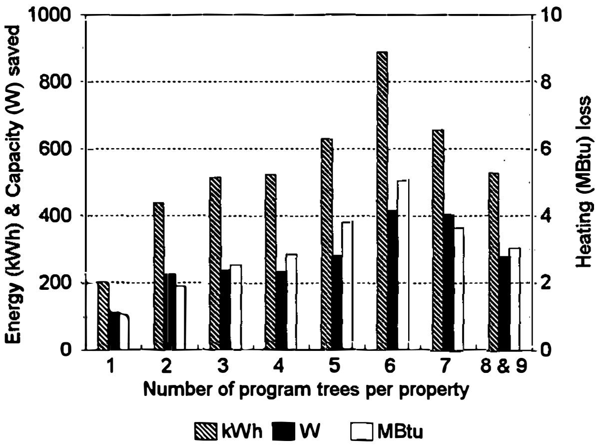

Figure 3. Normalized energy use impacts per property for program trees grouped by number of program trees.

Normalized annual air conditioning savings per tree (kWh) started near 200 kWh for 1 or 2 program trees per property, declining to approximately 150 kWh per tree for 3 to 6 trees before falling to 100 kWh or less for 7 or more trees (Figure 4). Similar patterns were observed for capacity (kW) and heating energy savings (Figure 4).

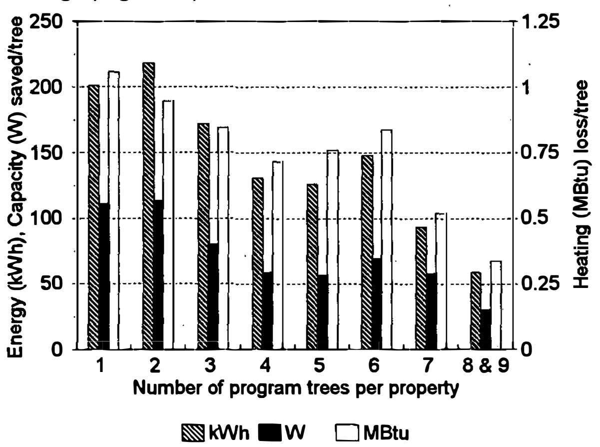

Figure 4. Normalized energy use impacts per program tree grouped by numbers of program trees.

3.4 *Climate Impacts*

A 7% increase in residential tree canopy cover was estimated 30 years after planting 500,000 trees. This was based on average lot area of ~930 m^2 (10,000 ft^2, extending to center of adjacent street), roof area of ~230 m^2 (2500 ft^2), and mature tree diameter/coverage of ~11 m/90 m^2 (35 ft/960 ft^2). It was assumed that ~1/3 of SMUD customers would receive trees, of which 2.2 per property (58%) would survive after 30 years. This is equivalent to an average increase of ~0.7 tree per residential property.

It was estimated that a 10% increase in canopy cover would reduce summer air temperature in Sacramento ~0.7°C based on simulations of local scale evapotranspirational cooling (Huang et al. 1987) and limited measured data from the Sacramento area (Taha et al. 1991, Sailor et al. 1992). Temperature coefficients for cooling used based on computer simulations (Huang et al. 1987, Sailor et al. 1992, McPherson 1994) were 10% °C^{-1} (kWh) and 2 to 6% °C^{-1} (kW; larger savings for newer vintages). Cooling impacts per 10% canopy cover increase are the product of temperature change resulting from increased cover and the temperature coefficient. Savings per tree is approximately the same, since one tree provides about 10% canopy cover (Table 1). Savings per property are ~70% as large, since there were on average ~0.7 trees per property.

Table1. Estimated residential cooling and heating impacts in Sacramento for direct shade, air temperature and wind speed reduction from trees.

Space Conditioning	Base case energy use	Savings per tree from:		
		direct shade	air temp.	wind speed
pre-1978				
Annual AC (kWh)	3507	7.3%	7%	-2%
Peak AC (kW)	5.0[a]	2.5%[a]	1.4%[b]	1%[b]
Annual heat (MBtu)	68.5	-1.8%	----	2%
post-1983				
Annual AC (kWh)	1689	7.6%	7%	-1%
Peak AC (kW)	2.4[a]	2.5%[a]	4.3%[b]	2%[b]
Annual heat (MBtu)	27.7	-2.5%	—	3%

[a]Average from 1 to 8 p.m.
[b]Average for peak hour

Wind speed reduction was estimated to be ~5% for a 10% increase in canopy, from measurements by Heisler et al. (1990). Space conditioning impacts per tree from this reduction (Table 1) were based on space conditioning simulations by Huang et al. (1990).

Annual and peak air conditioning energy savings were similar for direct shade and air temperature reduction (Table 1). Heating losses from direct shade were approximately compensated for by savings from wind speed reduction. Annual cooling losses from wind speed reduction were approximately compensated by savings for peak cooling.

Results indicate that net effects of trees on building space conditioning result from direct shade and air temperature reduction on annual energy and peak capacity for cooling. Savings from direct shade are comparable in magnitude to those from air temperature reduction. Effects from wind speed reduction, and from shade on heating, are of opposite sign resulting a small net effect.

4. ACKNOWLEDGEMENTS

This research was supported by funding from Sacramento Municipal Utility District and the USDA Forest Service. Special thanks are reserved for the insight and logistical support of Dr. Misha Sarkovich, SMUD Monitoring and Evaluation. The authors would also like to acknowledge participation of the Sacramento Tree Foundation.

5. REFERENCES

Akbari, H; Taha, H. 1992. The impact of trees and white surfaces on residential heating and cooling energy use in four Canadian cities. Energy. 17(2): 141-149.

Akbari, H., S. E. Bretz, J. W. Hanford, D. M. Kurn, B. L. Fishman, H. G. Taha and W. Bos. 1993. Monitoring peak power and cooling energy savings of shade trees and white surfaces in the Sacramento Municipal Utility District (SMUD) service area. Report LBL-34411, Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720.

Enercomp. 1992. Micropas4 v4.0 User's Manual. Enercomp, Inc. 1851 Heritage Way, Suite 187, Sacramento, CA 95815.

Huang, Y. J., H. Akbari, H. Taha and A. H. Rosenfeld. 1987. The potential of vegetation in reducing summer cooling loads in residential buildings. *J. Climate Appl. Meteor.* 26:1103-1116.

Huang, J.; Akbari, H.; Taha, H. 1990. The wind-shielding and shading effects of trees on residential heating and cooling requirements. ASHRAE Transactions. 96:1, 1403-1411.

Heisler, G. M. 1990. Mean wind speed below building height in residential neighborhoods with different tree densities. *ASHRAE Transactions.* 96:1, 1389-1396.

Heisler, G. M. 1991. Computer simulation for optimizing windbreak placement to save energy for heating and cooling buildings. In: Trees and sustainable development: the third national windbreaks and agroforestry symposium proceedings. Ridgetown, On: Ridgetown College: 100-104.

McPherson, E. G. 1994. Benefits and costs of tree planting and care in Chicago. In McPherson, E.G.; Nowak, D.J.; and Rowntree, R. (Eds.) Chicago's Urban Forest Ecosytem: Final Report of the Chicago Urban Forest Climate Project. USDA Forest Service, Northeastern Forest Experiment Station, Radnor, PA. p. 117-135.

McPherson, E. G., R. Brown and R. A. Rowntree. 1985. Simulating tree shadow patterns for building energy analysis. In A. T. Wilson and W. Glennie (eds.) Solar 85: Proceedings of the National Passive Solar Conference (pp. 378-382). Boulder, CO: American Solar Energy Society.

McPherson, E. G.; Sacamano, P. L. 1992. Energy savings with trees in Southern California. Tech. Rep. Davis, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Western Center for Urban Forest Research. 187 p.

Sailor, D. J., L. Rainer and H. Akbari. 1992. Measured Impact of neighborhood tree cover on microclimate, *In* Proceedings of the 1992 ACEEE Summer Study on Energy Efficiency in Buildings, Vol 9, p. 9.149-9.157, Washington, D.C.: American Council for an Energy-Efficient Economy.

Sand, M. A.; Huelman, P. H. 1993. Planting for energy conservation in Minnesota communities. Summary report for 1991-93 LCMR research project. St. Paul, MN: Department of Natural Resources, Forestry. 46 p.

Simpson, J. R., E. G. McPherson and R. A. Rowntree. 1994. Potential of tree shade for reducing building energy use in the PG&E service area. Final report to Pacific Gas and Electric Company, San Francisco, California.

Taha, H., H. Akbari, and A. H. Rosenfeld. 1991. Heat island and oasis effects of vegetative canopies: micro-meteorological field-measurements. *Theor. Appl. Climatol.* 44:123-138.

Thayer, R. and B. Maeda. 1985. Measuring street tree impact on solar performance: a five-climate computer modeling study. J. Arboric. 11:1-12.