Shade Trees as a Demand-Side Resource

Several utilities have embraced trees as a solar-powered demand-side management resource. What do we know so far about the effects of shade trees on building energy performance?

by Gregory McPherson and James R. Simpson

Many utilities are serious about the potential of shade trees as a demand-side management (DSM) resource. Tree planting and care partnerships with local community groups can also provide benefits beyond cost-effective energy savings. Shade tree programs offer opportunities for utilities to take civic leadership roles with respect to environmental issues, conservation education, neighborhood revitalization, and job training (see "Utilities Grow Energy Savings," p.14).

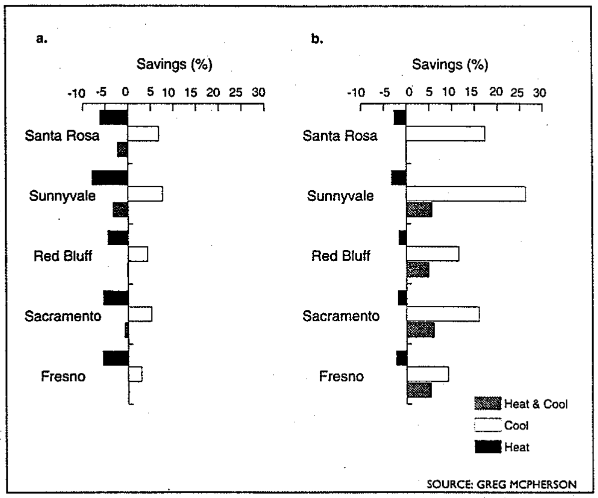
Shade trees reduce solar heat gain by transferring the active heat-absorbing surface from an inert building envelope to living foliage. Because the heat capacity of leaves is low, most of this energy is transferred to the surrounding air. If ample soil moisture is present and environmental conditions are suitable, water in the leaves evaporates in a process known as evapotranspiration and the air is cooled.

The evapotranspirational cooling produced by a single tree is difficult to measure because the cool air is rapidly diffused into the larger volume of air moving through the tree crown. However, large parks or residential neighborhoods with extensive vegetation can produce air temperature reductions as great as 10°F compared to nearby areas with little vegetation. At this neighborhood scale, large trees increase the aerodynamic roughness of the urban canopy layer, thereby reducing wind speeds by as much as 50%. Individual trees or massings near buildings can further modify air flow near buildings. Windspeed and air temperature modifications due to the aggregate effect of trees at the scale of a neighborhood are called "indirect effects." Shading of a building by trees, on the other hand, is a "direct effect."

Researchers measure tree trunk diameter while gathering data for the Chicago Urban Forest Climate Project.

GREG MCPHERSON

Trees can increase or decrease energy used for space conditioning. Shade is beneficial when it reduces solar heat gain during the cooling season, but detrimental in the heating season. Trees that overhang roofs can reduce radiative longwave infrared heat loss, especially to the cool summer sky at night, although the benefits of daytime shade outweigh this penalty. Wind shielding that reduces air infiltration



ART: KATHERINE FALK

Figure 3. Simulated annual heating, cooling, and total space conditioning energy savings for single 15-year-old deciduous trees (24-ft tall and 24-ft wide) planted opposite the south (a.) and west (b.) walls of a building with maximum insulation.

Micropas 4.0 to obtain estimates of energy savings. Computer simulations for cities across the United States indicate that shade from a single well-placed, mature tree (about 25-ft crown diameter) reduces annual air conditioning use by 2%-8% (40-300 kWh) and peak cooling demand by 2%-10% (0.15-0.5 kW). Simulations indicate that air temperature reductions associated with evapotranspirational cooling reduce annual cooling energy by 2%–8%, and reduce peak cooling by 1%-10% per tree. These findings suggest evapotranspirational cooling can produce air conditioning savings that rival those attributed to tree shade. Wind shielding from a single tree is projected to reduce annual use of natural gas for space heating by 1%-5%.

Shady Characters in California

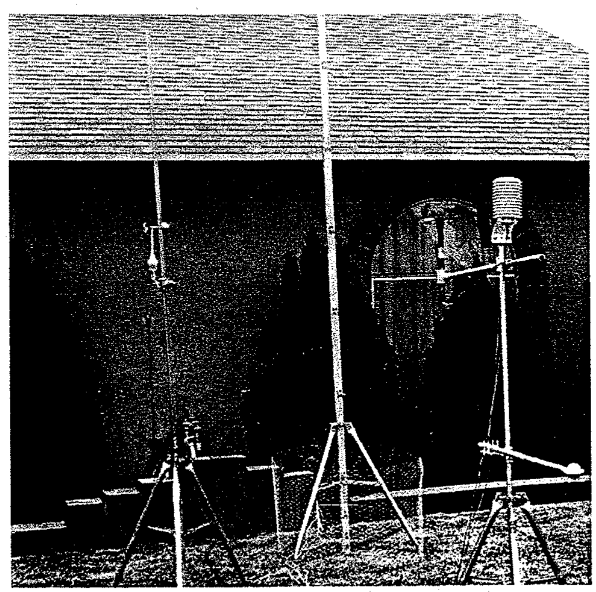
In a study of the five climate zones found in the service territory of Pacific Gas and Electric Company (PG&E) in central and northern California (Santa Rosa, Sunnyvale, Red Bluff, Sacramento, and Fresno areas), we simulated the effects of tree shade on peak and annual cooling and heating loads with computer models. Typical 5-, 10-, and 15-year-old trees were located singly and in groups on east, south and west sides of a single-story residence. We calculated peak and annual space conditioning energy use for the various shading and climate scenarios. In addition, we used three levels of wall and ceiling insulation: no insulation, R-19 in ceiling only, and R-38 in ceiling and R-19 in walls. This conservative analysis did not incorporate the effects of lower air temperatures and wind speeds often associated with increased urban tree cover.

We modeled a typical single-story frame house with characteristics consistent with California Energy Efficiency Standards (Title 24) for residential buildings as a test structure. Floor area was 1,500 ft^2 (slab-on-grade) and windows were evenly distributed (16% of floor area). Gas furnace efficiency was 78%, and the air conditioner SEER (Seasonal Energy Efficiency Rating) was 10. We assumed that cooling by natural ventilation occurred when outside temperatures dropped below the thermostat set point of 78°F.

We used a single deciduous tree species, the Chinese Lantern Tree (*Koelreuteria bipinnata*), to represent all trees in these simulations, and assumed the trees blocked 85% of incoming solar radiation when in leaf from April through November, and 30% during the December to March leaf-off period. At planting (15-gallon stock) and years five, ten and 15, tree height and crown diameter were 6-, 13-, 19-, and 24-ft, respectively. The rate of growth decreased with age from 1.5 to 1 ft per year, an extremely conservative growth rate for this tree in California. We investigated the impact of shade from individual trees on building energy use for trees growing opposite east, south, and west walls. We excluded the north wall because of the negligible shading that occurs there. We also simulated the effect of two trees on the west, and two on the west combined with one on the east.

Trees shading a west exposure had the largest impact on cooling savings (see Figure 2). In Sacramento, annual savings for a single 15-year-old tree on the west were up to 15% compared to the no shade case, or 450 kWh ($50). The addition of a second tree on the west was 80% of savings from the first tree on the west; savings from east and west trees were approximately additive. Savings for younger trees decreased in proportion to tree age, since younger trees shaded less wall area than the older trees with larger crowns.

Annual cooling savings were partially offset by small negative impacts of shade that reduced winter solar access and increased heating requirements. This energy penalty was most pronounced for trees on the south, and in near-coastal climates, where increases in heating load were larger than annual cooling savings, sometimes resulting in an increase in net space-conditioning costs. Obstruction of irradiance during the heating season by trees to the south



JIM SIMPSON

A weather station set up in the backyard of this southern California home measures temperature, wind speed and relative humidity. This particular set of instruments is gathering information used to determine the influences of tree cover on building microclimates.

Two young volunteers plant a tree for a very pleased resident.

program for 27 years, planting trees in right of ways near businesses and residences by request. Denison (Iowa) Municipal Utilities was a 1993 recipient of APPA's Golden Tree Award, and has already planted 2,900 trees. The Golden Tree Award is given to utilities who plant one tree for every public power customer in its service area. The Sanborn, Iowa Municipal Light Plant plans to develop a program that will plant four to five trees for each utility customer, and has established a municipal tree nursery to support that effort. In Rochester, Minnesota, the municipal utility is distributing coupons that customers can use toward the purchase of a tree at local nurseries. City Utilities of Springfield, Missouri has created the Tree Management Program operated by three full-time staff foresters. Customers of the City of Manassas, Virginia Electric Department buy trees at a 25% discount from participating nurseries, and get $10 off their next electric bill for planting it.

Trees Forever is a non-profit working with 300 communities, six investor-owned utilities, and seven municipal utilities in Iowa. According to Trees Forever president Shannon Ramsey, the organization has distributed 50,000 landscape size trees, roughly half of which are placed directly for energy efficiency. Trees Forever, started in 1989, had 25,000 volunteers in 1993, and more than 10,000 youths were involved.

—Abba Anderson

Abba Anderson is a freelance writer based in Forestville, California.

and east can be minimized by selecting "solar friendly" species such as redbud, green ash, and honey locust that have open crowns during the leaf-off period, drop their leaves relatively early during the fall, and leaf out in late spring.

In-leaf crown density and tree form influence the amount of building surface area shaded and air-conditioning savings. When selecting trees to maximize shade, tree form may be more important than crown density. For example, crown diameters of mature tree species can range from 10 to 50 ft, but the range of summer crown densities is relatively less, 60%–90% attenuation. A tall, narrow tree with a dense crown could produce less shade than a broad spreading, open-crowned tree in the same location. Trees with broad crowns and dense foliage provide the greatest shade.

Effects of Climate Zone and Insulation

Relations between cooling savings, climate, and building insulation level were consistent. As cooling degree-days and building insulation levels increased, annual percentage savings increased and absolute savings decreased. Three 24-ft tall shade trees reduced annual air-conditioning energy use 20%–50% (300–600 kWh, or $35–$70) for residences with R38/R19 insulation, 20%–40% (600–1,000 kWh, or $70–$130) for residences with R19/R0 insulation, and 10%–20% (800–1,100 kWh, or $90–$140) for those with no insulation. Annual air conditioning energy savings (kWh) for heavily insulated buildings were about 45% of the savings for uninsulated buildings, while percentage savings were two to three times greater for insulated compared to uninsulated buildings as a result of increased relative importance of solar gain through glazing on insulated structures.

Savings (kWh) in near coastal climates were two-thirds of those in valley climates because of the shorter cooling season and relatively cooler air temperatures in near-coastal climates. Percentage savings were about 50% greater in near-coastal climates since conductive gain is smaller due to lower air temperatures, so that solar gain becomes a relatively larger portion of total cooling load.

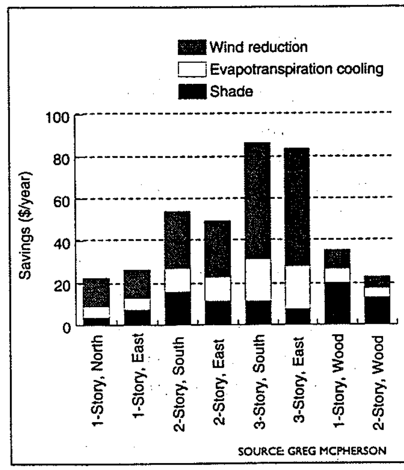


Figure 4. Simulated energy savings in dollars due to shade, evapotranspiration, and reductions in wind speed on a per-tree basis. (Shading savings are for single 36-ft tall and 24-ft wide deciduous trees opposite the west wall of each base-case building. Changes in evapotranspiration and wind speed are assumed to be associated with a 10% increase in overall neighborhood tree cover. Number of stories and front orientation of base-case buildings are listed.)

Trees Break Wind in Chicago

For residents of mid- and northern-latitude cities who pay more for space heating than cooling, wind protection from trees may be more valuable than summer shade. To evaluate potential heating and cooling savings, we ran computer simulations for five prototypical buildings: one-, two-, and three-story brick buildings similar to residences in Chicago, and one- and two-story wood-frame buildings representing suburban construction. (We validated energy performance of several prototypes by calculating building performance indices of occupied buildings using whole-house metered data and comparing results with indices of the simulated prototypes.) We simulated space heating and air conditioning savings due to tree shade, as well as evapotranspirational cooling, and wind shielding associated with a 10% increase in tree cover (corresponding to about three trees per building).

We projected annual space-heating savings of about $50 per tree (10 million Btu, 1.5%) for the three-story (six unit) buildings—$15–$20 more than air conditioning savings. Heat transfer in these large, old buildings (1930s construction) is dominated by infiltration and conduction. On the peak heating can be two to three times greater than costs for tree planting and care. Many of these benefits extend beyond the site where a tree grows, to influence quality of life in the local neighborhood, community, and region. Although the act of planting a tree is simple, it has a multitude of consequences that we are just beginning to discover.

Shade trees that are carefully selected, located, and maintained can be cost-effective energy conservation measures. However, the DSM benefits are highly site-specific, with greatest savings in areas with relatively long cooling seasons, large numbers of air-conditioned buildings, and ample space for new tree planting.

Further Reading

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7. *Energy-Efficient and Environmental Landscaping,* by Anne Simon Moffat, Marc Schiler, and the staff of Green Living. Appropriate Solutions Press, Dover Road Box 39, South Newfane, VT 05351. Tel: (802)348-7441.

Gregory McPherson is a project leader and James R. Simpson is a forest meteorologist, both with the USDA Forest Service's Western Center for Urban Forest Research at the University of California in Davis, California.