Where Are All The Cool Parking Lots?

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Problem Researched: This research focused on two problems related to tree shade in parking lots:

- Effects on climate and air quality,
- Costs and causes of non-compliance with ordinances requiring 50% shade on paved areas.

Background: The 1970s energy crisis spurred implementation of parking lot shading ordinances in cities such as Sacramento, Davis, and Los Angeles, California. These ordinances required that 50% of the total paved area be shaded within 15 years of the issuance of development permits. Tree Lists contained the 15-year crown diameter and crown projection area (i.e., area under a tree's dripline) of species recommended for planting, data used by landscape architects to calculate paved area that would be shaded under each tree. The Sacramento ordinance, adopted in 1983, ensures a distribution of shade throughout the lot and had not been evaluated or amended since its inception.

Parking lots occupy about 10% of the land in our cities and can be characterized as miniature heat islands and sources of motor vehicle pollutants. By cooling these heat islands, trees reduce air temperatures and vehicle hydrocarbon emissions. "Oasis effects" of 5 C to 7 C (9-12.6 F) have been measured due to direct shading of the ground surface and transpiration of water through leaves. By lowering parking lot temperatures, trees can reduce evaporative emissions of hydrocarbons (HC) from parked cars. These evaporative HC emissions account for 16% of total motor vehicle HC emissions in Sacramento, and motor vehicles are responsible for 49% of countywide HC emissions. During summer, HCs and NO_x form ozone through photochemical reactions. Currently, 159 million people live in areas where ozone concentrations violate federal air quality standards. Although the shading and cooling provided by parking lot trees was originally valued for energy conservation, air quality benefits may be important because increased air temperatures increase the rate of evaporative HCs released from leaky fuel tanks, worn hoses, and saturated carbon canisters.

Methods for Tree Shade, Climate, and Air Quality: The objective of this research component was to quantify vehicle HC emission reductions from three levels of parking lot tree shade in Sacramento County: 8% (current level), 25%, and 50% (as per ordinance). Temperature regimes were obtained from field measurements and used as input to a vehicle emissions model. Automated weather stations were deployed during July 22-28 and August 5-10 in shaded and unshaded portions of a shopping center parking lot in Davis, CA. Thermocouples measured air temperatures at half-meter intervals from 0.5 – 2.0 m above the ground every 15 seconds. Solar radiation, net radiation, wind speed and direction were also measured at each fixed station. The shaded station was located beneath a Chinese pistache (*Pistacia chinensis*) and canopy cover for the shaded portion of the lot was 29% based on aerial photo analysis.

Two identical Chevrolet Corsicas were located north of the fixed stations facing southwest. Cabin air temperature, as well as fuel tank interior and exterior temperatures were measured concurrently with fixed station variables.

The California Air Resources Board's MVEI7g model was run to estimate HC emissions from all light-duty vehicles in Sacramento County for a summer day, using air temperature input files representing hypothetical increases in regional parking lot tree cover (25% and 50%) from a base case (8% based on previous aerial photo analysis). Adjusted temperature regimes were constructed assuming that air temperature differences measured in the Davis parking lot study were due to canopy cover differences.

Methods for Costs and Causes of Non-Compliance: The objectives of this research component were to assess compliance with the 50% shade requirement, quantify the environmental and economic costs of non-compliance, and identify strategies to improve compliance. A citywide parking lot assessment used data from interpretation of black and white aerial photographs of Sacramento. A parking capacity analysis was conducted for a random sample of 15 parking lots selected by City of Sacramento Planning Department staff. The number of required parking spaces was calculated using parking ratios from the City ordinance and information on floor areas and dwelling units. The number of actual spaces and vacant spaces were counted in each lot between the peak use periods (Nov. 30 – Dec. 26). A tree survey and shading analysis was conducted for the same 15 lots. Trees in each lot were surveyed to obtain the following information: species, diameter at breast height, average crown diameter, shade credit, management needs, and vacant planting sites. An economic analysis was conducted to estimate the value of benefits associated with 1) 50% tree shade, as per the ordinance, 2) amount of tree shade typically achieved after 15 years under current conditions, and 3) amount of tree shade that exists at present. Annual benefits were estimated from results of the Sacramento Urban Forest Ecosystem Study on a unit tree canopy cover basis. To ascribe dollar values to benefits, air conditioning savings were directly estimated, while air quality, stormwater runoff, and other benefits were implied. For example, air quality benefits were estimated using prices that reflect the costs of reducing stationary source emissions in the Sacramento region. If it is cost effective for a corporation to pay $1/kg to reduce future emissions, then the air pollution mitigation value of a tree that absorbs or intercepts 1 kg of air pollution should be $1.

Results for Tree Shade, Climate, and Air Quality: During the warm period August 5-7 maximum daytime temperature reached 41 C (105 F) and temperature differences (unshaded minus shaded) were:

- 20 C (36 F) at the asphalt surface
- 1.3 C (2.3 F) at 0.5 m
- 26 C (47 F) in the cabin
- 2-4 C (4-8 F) in the fuel tank

Simulated HC emissions for the 50% canopy cover case were 0.85 tons per day less than the 8% canopy cover base case, representing a 3.3% reduction. This amounts to a 2% reduction of overall light-duty vehicle HC emissions (includes exhaust emissions). Though modest, the projected 2% HC reduction is comparable to the levels achieved through some of the local air quality district's currently funded programs (e.g., graphic arts, waste burning, alternative fuel stations).

Results for Costs and Causes of Non-Compliance: There were 6% more parking spaces than required by ordinance, and 36% were vacant during peak use periods. Current shade was 14% with 44% of this amount provided by covered parking. Shade was projected to increase to 27% when all lots in the sample were 15 years old. After inferring from the sample to all parking lots in Sacramento, annual benefits associated with 27% tree shade were estimated to be $1.8 million ($19.20/tree) annually, or $2.2 million less than benefits from 50% shade ($42.96/tree). The cost of replacing dying trees and addressing other health issues was $1.1 million. Planting 116,000 trees needed to achieve 50% shade was estimated to cost approximately $20 million.

Assuming trees reached their projected sizes in 15-year old lots, dry deposition of air pollutants accounted for 31% of estimated benefits, with ozone uptake the single largest value ($556,000). Aesthetic and other benefits accounted for 27% of total annual benefits ($479,000). Net atmospheric carbon dioxide reduction (17%) and air conditioning savings (11%) were estimated to produce combined benefits valued at about $500,000. The net HC benefit (12%) was valued at $208,000, with avoided evaporative emissions from motor vehicles due to tree shade (17,400 kg) nearly three times greater than the sum of biogenic HC emissions from trees and HC emissions associated with tree care (6,400 kg). Stormwater runoff reduction attributed to rainfall interception averaged 0.74 m^3 (214 gal) per tree (3% of total benefits). Strategies for revising parking ordinances to enhance their effectiveness follow.

During plan review and tree installation update the ordinance's Tree List to include more accurate estimates of 15-year crown diameter for a wider range of species. Provide planning staff with adequate time and training to review shade plans and parking ratios. Teach inspectors how to identify common problems in a systematic and thorough manner. Require certification by the landscape architect that parking spaces and trees are located as per the ordinance and plan.

During site planning and design reduce parking ratios to decrease the number of unused parking spaces. Identify peripheral and overflow parking areas, especially in retail lots, and determine the appropriate landscape treatment (e.g., pervious paving, stormwater infiltration areas). Narrow the width of aisles between rows of spaces. Increase the ratio of compact to full-sized spaces. Convert double-loaded full-sized spaces to compact spaces with a tree in between to increase shade without reducing the number of spaces. Increase use of one-way aisles, angled parking spaces, and shared parking to reduce overall imperviousness. Increase soil volume and reduce soil compaction. Increase tree well and planting island minimum dimensions to 2.4 m. Use structural soil mix under paving to retain parking spaces while increasing soil volume. Require soil in tree wells be excavated to a depth of 1 m and amended as necessary. Use vegetated swales instead of tree wells or convex-shaped islands to treat stormwater, promote infiltration, and increase soil volume for trees. Coordinate location of trees, light poles, and signs to reduce conflicts. Reduce the maximum height of parking lot light poles from 7.6 m to 4.9 m; the height trees are typically pruned for clearance. Amend sign ordinances to allow monument signs (eye-level signs located near the street) to have the names of major tenants listed on them and promote site designs that locate businesses closer to the street and move parking behind the buildings. Insure adequate species diversity (e.g., if 20-40 trees, no more than 50% same type, if more trees no more than 25% same type). Avoid tree species that are not suitable for parking lots (e.g., pines, poplars, birch), reliance on too many small-stature shade trees (e.g., crab apples, crape myrtle), and trees spaced too far apart.

After installation require that qualified professionals use proper tree care practices. Replace removed trees with trees of equivalent size or value according to a replacement schedule (e.g., a 10 cm tree is replaced by a tree in a 0.9 m box or a 15-gal tree and a $350 replacement fee). Develop an inspection program that records information on the management needs of every tree, and results in a letter sent to the property manager requesting corrective measures be made within a specific time frame. Failure to make the requested improvements could result in a fine or a lien on the property. Alternatively, an interest-bearing bond could be required initially to pay for landscape improvements throughout the life of the project.

Conclusions, Products, and Outcomes: This research has shown that well-treed parking lots can improve local air quality by reducing HC emissions from vehicles. US EPA adjusted the temperature reductions found in Sacramento for Chicago and developed HC reductions for 25% and 50% canopy cover scenarios using their computer model Mobile5b. This makes it possible for municipalities in the Chicago region to calculate HC reductions when seeking parking lot tree planting funds. Due to this research, the California Air Resources Board now recognizes properly designed parking lot tree planting as a voluntary measure for attaining air quality standards.

Research related to the Sacramento ordinance resulted in modifications to the City's "Parking Lot Tree Shading Design and Maintenance Guidelines." These changes directly addressed the causes of non-compliance noted above, and were formally approved by the City Council in 2003. Salt Lake City, Atlanta, and Los Angeles County are among many local governments that have used this research as a foundation for adopting or revising parking lot tree shade standards. Although this research is specific to the Sacramento area, approaches for evaluating the effectiveness of parking lot tree shade ordinances, as well as causes and remedies for non-compliance, have much broader application.

Products associated with this research include 3 peer-reviewed scientific publications, 2 popular articles, a poster, 2 newspaper articles (L.A. Times), 3 internal technical reports, a research summary, and 7 conference presentations.

This project touched on all phases of the research cycle: initial literature reviews and pilot studies, field measurements, computer modeling, statistical analysis, results reporting in scientific and popular formats, and ordinance revision. It has demonstrated the value of post-occupancy evaluation to both professional landscape architects and students. Initial work began in 1995 as a senior project for a student in the Landscape Architecture program at UC Davis, and has provided an opportunity for subsequent students to evaluate parking lot shade, quantify tree benefits, and develop landscape management recommendations. With a graduate student, we developed a 17 page "Parking Lot Shade Tree Inspection and Monitoring Guide" that contains illustrated protocols for TreeDavis trained volunteers to implement an ongoing enforcement program.

Parking lots are often barren seas of asphalt, testimony to the preeminence of car and commerce in today's culture. Monetizing the value of benefits foregone by the absence of trees makes the negative consequences on quality of life more tangible. Quantifying the value of "green infrastructure" is fundamental to leveraging investment from stakeholders (i.e., business, air quality management district, municipal utilities) and integrating it with other more readily perceived and measured infrastructure components such as parking lots, streets, and buildings.