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Actualizing Microclimate And Air Quality Benefits With Parking Lot Shade Ordinances

E. Gregory McPherson, James R. Simpson, and Klaus I. Scott*

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Extended Abstract

Parking lots have been recognized as thermal "hot-spots" and many California cities have implemented ordinances that require shading of 50 percent of paved areas by trees. Although these regulations have been in effect for over 15 years, relatively few lots achieve this level of canopy cover. Inadequate shade can increase air temperatures and pollutants emitted from parked cars. Parked cars emit evaporative hydrocarbons (HC) that contribute to the formation of ground level ozone. The

Photos of a parking lot before and after retrofitting.

hotter the car the higher the rate of evaporation from fuel tanks, hoses, and carbon canisters. A pilot study was performed to measure the difference in parking lot microclimate resulting from the presence or absence of shade tree cover in Davis, CA. A very modest level of shading resulted in an air temperature reduction of approximately 1 to 2° C (1.8 -3.6°F), compared to an unshaded lot.

The fuel tank in a shaded vehicle was 2 to 4°C (3.6-7.2°F) cooler than the tank in an unshaded vehicle, which suggests that irradiance and temperature reduction have approximately equivalent effects. Measured microclimate data were then used as input to a motor vehicle emissions model. Results indicate that increasing parking lot canopy cover from 8% to 50% would reduce Sacramento County's light-duty vehicle ROG evaporative emissions by 2% (0.85 tpd) and NOx start emissions by less than 1% (0.1 tpd). Though modest, these reductions are equivalent to projected emission reductions for existing air quality management district control measures for HCs and NOx (e.g., graphic arts, alternative fuel stations and waste burning, vehicle scrappage program). Measures to strengthen and more effectively implement Davis's Parking Lot Tree Shading Ordinance are described.

Actualizing Microclimate and Air Quality Benefits with Parking Lot Tree Shade Ordinances

Parking lots occupy about 10 percent of the land in our cities and 20 to 30 percent of the downtown core area (Beatty, 1989). They can be significant sources of heat, air pollutants, water pollutants, and visual blight. Because parking lots have been recognized as thermal "hot-spots," California cities such as Sacramento, Modesto, Los Angeles, and Davis have implemented ordinances that require shading of 50 percent of paved areas by trees. Although these regulations have been in effect for over 15 years, their effectiveness has been questioned. Furthermore, by lowering temperatures in parking lots, trees may improve air quality. Parked cars emit evaporative hydrocarbons (HC) that contribute to the formation of ground level ozone. The hotter the car the higher the rate of evaporation from the fuel tanks, hoses, and carbon canisters. To better understand how trees can improve parking lot environments our research is addressing the following questions:

1. Are municipal requirements for parking lot shade met, and if not, why?
2. How does parking lot shade influence microclimate, air temperature in particular?
3. How does parking lot shade effect evaporative HC emissions from parked cars?
4. Can parking lot tree planting and stewardship programs be cost-effective HC control measures?
5. What are key elements to implementing successful parking lot tree shade ordinances?

This paper focuses on our parking lot microclimate measurements, modeling of regional HC emission reductions associated with increased parking lot tree canopy cover, and efforts to amend the City of Davis ordinance to increase parking lot tree shade.

1. Background

Like many urban areas of the U.S., Sacramento, California has summertime episodes when ozone concentrations violate the federal air quality standard. Ozone is formed through atmospheric photochemical reactions involving precursors such as oxides of nitrogen (NO_x) and hydrocarbons in the form of "reactive organic gases" (ROGs). To reduce the ozone problem, air quality agencies seek to reduce NO_x and ROG emissions, especially from mobile (vehicles) sources. Vehicles are major sources of NO_x (68%) and ROGs (49%) in Sacramento (ARB, 1995). While vehicle ROG emissions are largely in the form of tailpipe exhaust, approximately 8.8 metric tonnes per day (9.1 ton per day) (16%) are in the form of evaporative emissions when vehicles are not operating. "Diurnal" emissions occur during daytime heating of fuel delivery systems. "Resting loss" emissions occur during periods of constant or decreasing air temperature. "Hot soak" emissions occur during the hour following engine shut-down. "Start" emissions occur during the first few minutes of engine operation and are dependent on both ambient temperature and the duration that an engine is off prior to a start. Diurnal, resting loss, hot soak and start emissions are sensitive to local air temperature, which are influenced by local meteorological and microclimate conditions. In California planners use a motor vehicle emission inventory model (MVEI7G) to calculate the air pollutant burden posed by the region's motor vehicles (ARB, 1996). MVEI7G utilizes temperature-dependent emission factors and county-specific temperature files to compute emissions.

Unshaded parking lots can be characterized as miniature heat islands and sources of motor vehicle pollutants (Hahn and Pfeifer,1994; Asaeda et al., 1996). Tree canopies can cool these "hot-spots" by direct shading of the ground surface and indirectly by the transpiration of water through leaves (Lee, 1978; Oke, 1987). Air temperature differences of approximately 2 to 4°C (3.6-7.2°F) have been observed for urban neighborhoods of contrasting tree cover, averaging approximately 1°C (2°F) per 10% canopy cover (Huang et al., 1987; Myrup et al., 1993; Simpson et al., 1994). In Sacramento, temperature differences of 5 to 7°C (10-14°F) have been observed for suburban and unirrigated rural surroundings (Grimmond et al., 1993). Through cooling of heat islands, urban forests may affect vehicle hydrocarbon emissions (Cardelino and Chameides, 1990; Taha, 1996; Scott et al., 1999).

Though parking lot tree shade ordinances in many California cities require that lots shade 50% of paved areas 15 years after development, personal observation and one study suggest that few lots attain this goal. Field surveys of 5 lots in Davis, CA indicated a wide variability in parking lot canopy cover, ranging from 8% to 45% and averaging 25% (Wong, 1996). Factors responsible for noncompliance included: selection of inappropriate tree species (e.g., low branching, weak-wood, messy, intolerant to drought, susceptible to diseases and pests), soil environment incapable of supporting healthy and vigorous tree growth (e.g., inadequate soil volume, low permeability, and poor irrigation), tree maintenance not geared towards achieving compliance (e.g., dead trees not replaced, trees are topped or pruned to reduce crown spread), and trees spaced too far apart given actual growth rates.

2. Objectives

A pilot study was conducted to estimate regional vehicle hydrocarbon emissions reductions potential of parking lot shade trees, using measured temperature data and a vehicle emissions model. Parking lot climate was monitored to address differences between (1) shaded and unshaded parking lot air temperature and (2) shaded and unshaded vehicle temperature.

3. Methods

3.1 Field Site

A retail shopping center parking lot containing shaded and unshaded portions was located in Davis, California (Figure 1), a community approximately 120 km (75 mi) northeast of San Francisco, located in California's Central Valley. Within a radius of approximately 0.3 km (0.2 mi) the shopping center was surrounded by residential neighborhoods composed primarily of single family houses and many mature shade trees. The parking lot street frontage was approximately 180 m (590 ft) long, while the depth was approximately 48 m (157 ft). The tree-shaded eastern portion of the lot was located in front of a market and comprised approximately 40% of the total parking lot area. The amount of paved area and tree canopy cover was determined from ground and aerial photo data (Elliott, 1986; Wong, 1996; McPherson, 1998). Percentage canopy cover was determined from analysis of aerial photos taken August 18, 1995. A model CI-100 Digital Plant Canopy Imager was used to measure the transmission of hemispheric diffuse radiation of tree canopies located at 11 mobile transect stops in the shaded parking lot. The transmission coefficient (TC) or sky view factor is an indication of the density of canopy cover and is used to define a "shading factor" (SF) to describe irradiance reduction by plant canopies such that $SF = (SA_S)(1 - TC) / SA_T$, where SA_S is the surface area shaded (fractional canopy cover x total area of interest), the quantity (1-TC) is a surface shading coefficient (where TC is the average transmission coefficient) and SA_T is the total area of interest (McPherson et al., 1988).

3.1.1 Fixed Stations. Automated weather stations were deployed to simultaneously measure climate variables (air temperature, wind speed, solar and net radiation) in an unshaded and shaded parking stall for two separate periods, July 22-28 and August 5-10 1997. The August period was marked by a typical warm regime and results are discussed below. Sensors were serviced and calibrated at the manufacturer prior to use. Each fixed station was comprised of two tripods, one mounted with a vertical mast of fine-wire thermocouples constructed of unsheathed fine gage (0.025 mm diameter) copper-constantan thermocouple wire at half-meter intervals (0.5, 1.0, 1.5 and 2.0 m)(1.6, 3.3, 4.9 and 6.6 feet), the other rigged with a vertical mast and cross-beam mounted with a LI-COR LI200S pyranometer, REBS Q*6.70 net radiometer, and R.M. Young 03001 wind set (measurement height 1.5 m). Each instrumented tripod was connected to a Campbell Scientific CR10 datalogger and battery. Sensor readings were performed every 15 seconds and stored as 5 minute averages. The shaded station was located beneath a Chinese pistache (Pistacia chinensis) with a bole height of 2.6 m (8.5 ft) and crown radius of 4.5 m (14.7 ft). Tripods were approximately 2.5 m (8.2 ft) from the tree trunk. A nearby Chinese elm (Ulmus parvifolia) also shaded the site. Temperature differences between shaded and unshaded sites were computed as $\_T(t) = T(t)_{shade} - T(t)_{sun}$, where T(t) is average temperature for the interval ending at time t.

3.1.2 Mobile Transects. Walking transect measurements were performed on August 6 to estimate spatially averaged air temperature in the shaded and unshaded parking lots. Transect stops were made in parking stalls (rather than travel lanes) and consisted of stationary readings at 11 different stops on a circuit originating and ending at respective fixed climate monitoring stations. Twenty-three transects were performed in the shaded lot and twenty-two in the unshaded lot. Air temperature measurements were made using a CORECI type IHRT hand held sensor and pavement and vehicle surface temperatures were made using an Everest Interscience Model 130.2L Infrared Thermometer. In addition, a transect was performed to collect images of individual tree canopies using the CI-100.

3.1.3 Vehicles. Two vehicles of the same make, model (1996 Chevrolet Corsica) and color (dark metal flake blue) were co-located on the north side of the fixed stations. Vehicles were oriented with front ends facing southwest. Cabin air temperature and fuel tank interior temperature were monitored concurrently with fixed station climate variables. Thermocouples were inserted in the fuel tank via the fill line. A fine-wire thermocouple was mounted in the vehicle cabin between the front driver and passenger seats at shoulder height.

3.1.4 Field calibration. Sensor comparisons were performed both prior to and after field use. Average differences or offsets between paired sensors developed from these side-by-side comparisons were small and less than manufacturer specified errors, so that manufacturer specifications are used to define minimum differences that can be resolved. Computed differences between shaded and unshaded regimes are therefore reported below without adjustment for offsets, except for the comparisons between spatially averaged (mobile transect) versus fixed station air temperature. Because different sensors were used for the walking transect versus fixed measurements, it was necessary to compute offsets between the spatial average and fixed station air temperature. Overall, temperature differences are measured to within 0.3°C (0.5 °F).

3.2 Emissions Modeling

The MVEI7G model was used to evaluate regional impact of contrasting parking lot climate regimes on vehicle emissions for Sacramento county. The model represents the contribution of various types of vehicle categories, fuels, emission controls and travel activity to total emissions for a summer day.

The MVEI7G model employs county average ambient temperature data (in °F) for ten days with the worst (pollutant specific) air quality readings over the period 1987 to 1989. The "default" county temperature input therefore represents historical typical meteorological conditions for days when an air quality standard is violated. To simulate emission reductions associated with full compliance with local parking lot shade ordinances, an increase in regional parking lot tree cover from a base case 8% canopy cover to 50% was assumed. Output from the base case run quantified the emissions for the model default county temperature regime, where the county-wide parking lot tree canopy cover is estimated to be 8% (Rowntree and Kerkman, 1997). For the 50% case, temperatures are adjusted from the base case temperatures, using proportional temperature differences between the shaded and unshaded parking lot sites.

To construct adjusted temperature regimes, it was assumed that the temperature difference between shaded and unshaded parking lot sites in each period was due to a difference in the percentage canopy cover. To estimate the temperature adjustment from the base case, the period-specific temperature rate of change (derived from the parking lot result) was multiplied by the canopy cover increase from the base case, and the product subtracted from the base case period temperature

$$Ta_i = Tb_i - (CCI \times (\_T_i / \_CC))$$

where:

Ta_i = the temperature adjusted with respect to canopy cover increase for period i

Tb_i = the base case temperature for period i

CCI = canopy cover increase (e.g., 42% for an increase from 8% to 50% canopy cover)

$\_T_i = T_{unshaded\ site} - T_{shaded\ site}$

_CC = difference in canopy cover between unshaded and shaded parking lot sites (i.e., 42%)

4. Results

4.1 Parking Lot Measurements

Aerial photo image analysis of the shaded portion of the lot, taken in August 1995, estimated shade tree canopy cover at 29% (Wong, 1996)(Figure 1). In August, many of the Chinese elms (Ulmus parvifolia) were losing foliage due to drought stress. From 11 images (corresponding to individual walking transect stops), transmission coefficients for hemispherical diffuse radiation ranged from 0.10 to 0.77, averaging 0.37, where increasing transmission coefficients indicate decreasing canopy density (e.g., less shade). The parking lot shading factor (SF) was equal to 0.18. These measures confirmed visual observation that canopy density was sparse and variable. Climate differences between shaded and unshaded parking lots inferred from measurements discussed below are therefore conservative.

4.1.1 Synoptic Conditions. Skies were cloud-free on August 5-10 and daytime temperatures were warm. Maximum daytime temperatures occurred on August 7, exceeding 41°C (105.8 °F) at the unshaded parking lot site. As a result of a southward migration of the high pressure ridge, an afternoon sea breeze regime returned by August 8, resulting in cooler daytime highs for August 8-10. Therefore, August 5-7 are defined as a warm period, with August 8 a transition to a cooler regime for August 9 and 10. Daytime wind speeds for the warm period August 5-7 were light, averaging 0.5 m s^{-1} (1.1 mi hr^{-1}) from a southerly direction during the afternoon. On August 8-10 afternoon wind speeds exceeded 1 m s^{-1} (2.2 mi hr^{-1}) and came from south and west.

4.1.2 Parking Lot Air Temperature. During the warm period August 5-7 afternoon maximum temperatures (hourly average, all heights) at the unshaded site exceeded 40°C (104°F), while maximums at the shaded site were approximately 1°C (1.8°F) less. The daytime maximum temperature on August 8 at the unshaded site was approximately 37°C and decreased on successive days to approximately 29 and 26°C (84.2°F and 78.8°F). Temperature differences (Figure 2a) between the shaded and unshaded site were less pronounced during the cooling trend of August 8-10, averaging -0.6°C (-1.08°F).

The difference between the spatial average and the fixed station air temperature averaged +0.26°C (s = 0.30°C) for the shaded lot and -0.003°C (s = 0.33°C) for the unshaded lot, suggesting that fixed station measurements were representative of parking stall temperatures in shaded and unshaded lots.

4.1.3 Vehicle Temperatures. Maximum fuel tank temperatures during the August 5-7 warm period for the unshaded vehicle averaged 41.6°C (106.9°F) and 38.6°C (101.5°F) for the shaded vehicle. Temperatures inside the shaded vehicle fuel tank ranged from 2.1 to 3.7°C (3.8°F to 6.7°F) less than those for the unshaded vehicle. When averaged with respect to hour of the day over the August 5-7 warm period, shaded fuel tank temperatures were coolest during the hours from 17:00 to 20:00 PST by approximately 3.1°C (5.6°F), compared to the unshaded vehicle (Figure 2b).

Cabin temperatures were markedly different between shaded and unshaded vehicles. During the August 5-8 period cabin temperature exceeded 65°C (149°F) in the unshaded vehicle while the shaded vehicle maximum temperatures were less than 50°C (122°F). When averaged with respect to hour of the day during the period August 5-7, cabin temperatures in the shaded vehicle were cooler by approximately 26.2°C (47.2°F) during the hours from 13:00 to 16:00.

4.1.4 Microclimate Differences. Observed temperature differences between shaded and unshaded vehicle fuel tanks, which are larger in magnitude than air temperature differences, indicate that irradiance and air temperature reductions have similar effects on evaporative hydrocarbon emissions. At this very modest level of shading trees exerted an air temperature reduction of approximately 1 to 2°C (1.8 -3.6°F), compared to unshaded lots. The shaded fuel tank was 2 to 4°C (3.6-7.2°F) cooler than the unshaded, suggesting that irradiance reduction contributes another 1 to 2°C reduction in fuel tank temperature. Based on observed daytime parking lot occupancy, users appeared to select shaded parking stalls over stalls with less shade. This implies that trees could be strategically located near entrances, employee parking areas, and other preferred parking locations to increase air quality benefits.

4.2 Emissions Modeling: 8% vs. 50% Tree Cover

ROG diurnal emissions for the 50% canopy cover case were 7.5% less than the base case

(8% canopy cover), while hot soaks were 4% less than the base case (Table 1). Although ROG emissions from starts were reduced by 2.5% from the base case, the tonnage reduction (14.93 - 14.55 = 0.38 tpd) was as great as the reductions from diurnal and hot soak emissions combined (0.41). ROG emissions for the 50% canopy cover case were 0.77 metric tonne per day (tpd) less than the 8% canopy cover base case, representing a reduction of 3.3%. For the 50% canopy cover case, NOx reduction was 0.1 tpd. The starts, evaporative diurnal, hot soak and resting loss ROG emissions are however only a part of the total ROG emissions, which include "running exhaust" and "running losses." For the 50% canopy cover case, total ROG emissions are 26.70 tpd for light-duty autos (LDAs) and 12.18 for light-duty trucks (LDTs). Taken together, the 0.77 tpd ROG reduction represents a 2% reduction of the over-all light-duty vehicle ROG emissions. Similarly, the starts NOx reduction represents a small portion (0.2%) of the total light-duty vehicle NOx emissions.

5. Parking Lot Tree Shade Ordinance Amendments

City of Davis staff have been working with Forest Service researchers to recommend amendments to the City's Parking Lot Tree Shade ordinance. The ordinance was adopted in 1979 and remained unchanged until 1997. A 1996 report (Wong) describing causes for the limited success in establishing healthy tree canopies in parking lots prompted the City Planning Commission to strengthen the ordinance. In 1997 a set of interim changes were approved by the Planning Commission addressing some of the simpler issues such as development of an improved parking lot tree list and simplified shading calculations. Recently, a second set of changes have been proposed that address more complex issues. These changes have been reviewed and approved by the City Planning and Street Tree Commissions, and await final approval by the City Council. Changes to the ordinance are reviewed below and additional information is available from the authors.

5.1 Parking Lot Shading Calculations

A parking lot shading plan is required for Planning Department review. The plan shows all paved areas included in the shading calculation (all surfaces on which vehicles maneuver) and trees drawn to scale with crown sizes at 15 years. Appropriate crown sizes are provided for each species on the approved tree list. Only trees from this list may be used unless otherwise approved by the city arborist. Each tree receives 25%, 50%, 75%, or 100% shading credit based on the percentage of crown projection area above paved areas. For example, a tree with a 10.7 m (35 ft) crown diameter (89 m^2 crown projection area) at 15 years located on the perimeter of the lot receives 50% credit or 44.7 m^2 (481 ft^2). The shade calculation table lists the number of each tree species receiving 25%, 50%, 75%, or 100% shading credit. Also, credit is given to existing trees and tall structures located so as to shade the lot.

5.2 Minimum Planter Sizes

Optimal soil volume estimates have been developed for different tree species and sizes (Lindsey and Bassuk, 1991; Koppinga, 1998). Ideally, the soil volume is sufficient to provide enough water holding capacity and nutrients for trees to grow at their potential rate. Our data on street tree growth rates indicate that fifteen years after planting a healthy shade tree in Davis should grow to 25 to 38 cm (10-15 inch) diameter at breast height (dbh), with a crown projection area of 30 to 60 m^2 (320-645 ft^2), and height of 7.5 to 12 m (25-40 ft). Given the richness of local soils, models suggest a demand of about 0.5 m^3 of rootable soil per m^2 of crown projection, or 15 to 30 m^3 (530-1,059 ft^3) for a 15 year old tree. A standard tree well 1.2 m by 1.2 m by 0.6 m deep (4 ft x 4 ft x 2 ft) provides less than 1 m^3 (35 ft^3) of soil volume. Thus, soil volumes in parking lots are seldom sufficient to promote healthy tree growth. Another limitation is compaction of soil surrounding the hole. This inhibits roots from "breaking out" of the hole into which they are planted. Breaking up compacted soil near the planting site will promote tree establishment.

The City's Street Tree Commission has recommended a minimum 2.4 m by 2.4 m by 0.9 m deep (8 ft x 8 ft x 3 ft) planting area for each tree planted in a tree well or planter strip. A minimum 1.8 m by 2.4 m by 0.9 m deep (6 ft x 8 ft x 3 ft) area is being considered for planters that extend into the lot (island planters). These dimensions provide 4 to 5 m^3 (144-192 ft^3) of rootable soil volume before tree roots "break out" into the surrounding subsoil. To avoid losing parking stalls, these larger tree wells can be placed between facing stalls for compact cars by reducing stall length from 5.8 m to 4.6 m (19-15 ft). Also, these dimensions provide sufficient distance to protect tree trunks from vehicle bumpers overhanging the curb.

Another way to increase tree soil volumes while not reducing the number of parking stalls is to install a structural soil mix under the paving (Grabosky et al., 1998). This mix is a load-bearing matrix of coarse stone aggregate, topsoil, and binding agent that can be extended out from around the tree well at a minimum depth of 0.6 m (2 ft). By placing the structural soil mix under the asphalt to 2.4 m (8 ft) from a tree well, the rootable soil volume is increased to 31 m^3 (1,100 ft^3). The structural soil mix supports automobile and pedestrian traffic, and the pores created by the mix make it suitable for root development. Preliminary cost estimates suggest that although the cost of structural soil mix is comparable to topsoil, the total installation cost is substantially greater than for the traditional tree well because a larger amount of material is used and site preparation and installation costs are increased. Installation and evaluation of a structural soil mix is underway at a parking lot in Davis.

5.3 Planting and Irrigation Details

Initial guidelines did not have specifications on how to best plant and irrigate trees. A new planting detail requires excavation of the planter to 0.9 m (3 ft) depth, installation of a 0.6 m (24-inch) linear root barrier to protect the curb and pavement from roots, and use of uncompacted backfill except under the rootball (Figure 3). This detail should reduce soil compaction that can limit root growth. Irrigation is from a minimum of two bubbler or stream spray heads, each located in a deep watering tube. The rock-filled tubes will promote deeper rooting and improve soil aeration.

5.4 Conflicts with Parking Lot Lighting and Business Signs

The typical height of a parking lot light pole is 7.6 m (25 ft). The crowns of mature trees are generally this height, often resulting in light obstruction. Pockets of unilluminated areas create safety hazards and insurance companies have required property owners to remove trees that are obstructing the light source. Staff has recommended a maximum height of 4.9 m (16 ft) for parking lot light poles in new commercial, industrial, and multifamily projects. The 4.9 m height conforms with the common practice of pruning tree branches up to about this height for vehicle clearance. This requirement will increase costs to developers because additional light poles will be needed to illuminate the area. However, having more light sources distributed throughout the parking lot will create a more even distribution of light and a safer environment for users.

While parking lot trees are young the wall signs of businesses are highly visible to customers driving on the street and in the lot. As the trees grow they create a visual barrier between the street and the building wall sign. Property owners and business owners are forced to prune or remove trees to improve visibility of their signage. One solution to this conflict is to locate businesses closer to the street and move parking behind the buildings. This site design concept has been included in the City's Draft General Plan. In addition, changes are recommended to the sign ordinance to allow monument signs (eye-level signs located near the street) to have the names of major tenants listed on them.

5.5 Maintenance and Monitoring

The existing guidelines require a site plan showing compliance with the 50% shading ordinance and a site check after construction to ensure consistency with the plan. Verification of compliance typically ends there. The ordinance does not require replacement of dead trees and use of correct pruning practices. There is no mechanism for monitoring compliance.

The Street Tree Commission has recommended a series of statements regarding tree care and maintenance to ensure that proper practices are used by qualified professionals. Also, removed trees are to be replaced with trees of equivalent size or value according to a replacement schedule (e.g., a 10 cm [4 in] tree is replaced by a tree in a 0.9 m [36-in] box or a 57 liter [15-gal] tree and a $350 replacement fee).

An innovative solution to monitoring proposes using trained volunteers to conduct inspections and report findings to the City and property owner. The local non-profit Tree Davis will coordinate the effort and train volunteers. Inspections will be conducted 8 times over the 15 year period following construction (years 1, 2, 3, 5, 7, 9, 12, 15). During inspections information is recorded on the health and management needs of every tree. Measures required to improve tree health and correct problems are noted on the inspection sheet. A brief letter with the inspection sheet attached is sent to the property owner describing inspection results and requesting corrective measures be made within a specific time frame. Although use of volunteers and environmental education grants will limit costs, the City will still incur administrative costs to coordinate inspections and ensure follow-up with owners. To offset these costs an inspection fee is proposed that ranges from $450 (U.S.) for all 8 inspections in lots with 10 to 50 stalls to $2,400 (U.S.) for lots with more than 500 stalls. It is recommended that the total fee be paid at time of building permit issuance to avoid an on-going billing process.

6. Discussion

Meteorological observations show that even sparse tree canopy exerted a cooling effect on both parking lot climate and vehicle temperature. Motor vehicle emission model scenarios indicate that increasing parking lot canopy cover from 8% to 50% would reduce Sacramento County's light-duty vehicle ROG evaporative emissions by 2% (0.77 tpd) and NOx start emissions by less than 1% (0.1 tpd). The projected motor vehicle ROG percentage reductions in Sacramento are in reasonable agreement with spatially resolved, urban heat island model results for the Los Angeles basin, where mobile source emissions were reduced by 1.5% (Taha, 1997). Though modest, the projected ROG reductions (0.77 tpd) are equivalent to projected hydrocarbon emission reductions for existing air quality management district control measures for graphic arts, ethylene oxide sterilizers, alternative fuel stations and waste burning (totaling 0.81 tpd) (SMAQMD, 1994). Projected NOx emission reductions (0.1 tpd) are equivalent to reductions projected from the district's light-duty vehicle scrappage program (0.1 tpd) (SMAQMD, 1994).

The MVEI7G modeling results did not account for irradiance effects on vehicle temperature. By analogy with the "equivalent blackbody temperature" concept used in biophysical energy budget studies, an "effective" air temperature could be developed. An effective air temperature input to the MVEI7G model, incorporating both air temperature and irradiance reduction due to tree canopy cover, would presumably predict greater emission reductions resulting from shade. At the same time, an effective air temperature may also better predict emissions for unshaded conditions where both air temperatures and irradiance are high. In addition, because a large fraction of the modeled ROG emission reductions were from starts, reduced cabin air conditioning use could substantially reduce tailpipe emissions.

These results indicate that a large-scale parking lot tree planting and stewardship program could potentially result in considerable air quality benefits. Current research is evaluating the cost effectiveness of alternative programs. Our analyses are incorporating the full range of costs, such as biogenic hydrocarbon emissions by various tree species; ROGs emitted by chain saws, chippers, and other equipment used to maintain trees; repair to curbs and paving caused by tree roots, as well as expenditures for planting, pruning, and removal. Benefits include dry deposition and interception of particulates by trees. Program alternatives assume different levels of participation by contractors and trained volunteers over the 40-year analysis period.

Strengthening the Parking Lot Shading Ordinance through recommendations that address design, maintenance, and enforcement should result in more successful shading of new lots. Currently, we are developing a training manual for volunteers who will be inspecting the lots. The manual will help ensure that data are collected and recorded in a standardized manner and that periodic data quality control checks are implemented.

There is need to obtain funding to retrofit existing lots that are not well-shaded since businesses are unlikely to pay the full costs for this voluntarily. Our measurement and modeling results suggest that air quality benefits might be of interest to local air quality districts. Stormwater management agencies are another possible source of funding if retrofits address the potential to reduce polluted runoff through bioswales, filter strips, and use of pervious materials in spillover parking (Center for Watershed Protection, 1998). Trees could be purchased through existing grant programs for urban and community forestry. Having a proven monitoring program that tracks the growth, health, and mortality of parking lot trees should encourage investment by funding agencies concerned with obtaining long term environmental benefits for the public. Multi-agency partnerships with local businesses and non-profits offer a viable means for demonstrating how parking lots can be redesigned, planted, and monitored to achieve environmental, economic, and aesthetic benefits.

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8. References

Air Resources Board, 1995: **Emission Inventory**. Technical Support Division. Sacramento, CA.

Air Resources Board, 1996: **Methodology for Estimating Emissions from On-road Motor Vehicles. Volume 1: Introduction and overview**. Technical Support Division, Mobile Source Emission Inventory Branch. Sacramento, CA.

Asaeda, T., Ca V.T., and Wake, A., 1996: **Heat Storage of Pavement and its Effect on the Lower Atmosphere**. Atmospheric Environment: Urban Atmosphere. 30, 413-427.

Beatty, R.A., 1989: **Planting Guidelines for Heat Island Mitigation and Energy Conservation**. In Garbesi, K. et al. (eds). Controlling Summer Heat Islands, Berkeley: Lawrence Berkeley Laboratory.

Cardelino, C.A. and Chameides W.L., 1990: **Natural Hydrocarbons, Urbanization and Urban Ozone**. Journal of Geophysical Research. 95:13971-13979.

Center for Watershed Protection, 1998: **Better Site Design**. Ellicott City, MD: Center for Watershed Protection.

Elliott, K. E. 1986: **Tree Shade in Urban Parking Facilities: An Evaluation of Parking Patterns and the Davis Mandatory Shade Ordinance**. Thesis. Department of Geography. University of California. Berkeley.

Grabosky, J., Bassul, N., Irwin, L. and van Es, H., 1998: **Pilot Field Study of Structural Soil Materials in Pavement Profiles**. In Neely, D. and Watson, G. (eds) The Landscape Below Ground II, Champaign, IL: International Society of Arboriculture.

Grimmond, C.S.B., Oke, T.R. and Cleugh, H.A., 1993: **The Role of "Rural" in Comparisons of Observed Suburban-rural Flux Differences**. In: Exchange Processes at the Land Surface for a Range of Space and Time Scales. Proceedings of the Yokohama Symposium. July 1993.

Hahn, H.H. and Pfeifer, R., 1994: **The Contribution of Parked Vehicle Emissions to the Pollution of Urban Run-off**. The Science of the Total Environment. 146/147, 525-533.

Huang, J., Akbari, H., Taha, H. and Rosenfeld, A., 1987: **The Potential of Vegetation in Reducing Summer Cooling Loads in Residential Buildings**. Journal of Climate and Applied Meteorology. 26, 1103-1116.

Kopinga, J., 1998: **Evaporation and Water requirements of Amenity trees with regard to the Construction of a Planting Site**. In Neely, D. and Watson, G. (eds) The Landscape Below Ground II, Champaign, IL: International Society of Arboriculture.

Lee, R., 1978: **Forest Microclimatology**. Columbia University Press. New York.

Lindsey, P. and Bassuk, N., 1991: **Specifying Soil Volumes to Meet the Water Needs of Mature Urban Street Trees and Trees in Containers**. Journal of Arboriculture. 17, 141-149.

McPherson, E.G., 1998: **Structure and Sustainability of Sacramento's Urban Forest**. Journal of Arboriculture. 24, 174-190.

McPherson, E.G., Herrington, L.P. and Heisler, G.M., 1988: **Impacts of Vegetation on Residential Heating Cooling**. Energy and Buildings. 12, 41-51.

Myrup, L.O., McGinn, C.E. and Flocchini, R.G., 1993: **An Analysis of Microclimatic Variation in a Suburban Environment**. Atmospheric Environment. 27B, 129-156.

Oke, T.R., 1987: **Boundary Layer Climates**. New York: Methuen.

Rowntree, R. and Kerkman E., 1997: **Urban Forest Canopy Cover in California: Analysis of 21 Cities and Towns**. Unpublished technical report. USDA Forest Service, Pacific Southwest Research Station. Albany, CA.

Sacramento Metropolitan Air Quality Management District, 1994: **Post-1996 Rate of Progress Plan for Ozone**. Sacramento: Sacramento Metropolitan Air Quality Management District.

Scott, K.I., Simpson, J.R. and McPherson, E.G., 1999: **Effects of Tree Cover on Parking Lot Microclimate and Vehicle Emissions**. Journal of Arboriculture. 25, 129-142.

Simpson, J.R., Levitt, D.G., Grimmond, C.S.B., McPherson, E.G. and Rowntree, R.A., 1994: **Effects of Vegetative Cover on Climate, Local Scale Evaporation and Air Conditioning Energy Use in Urban Southern California**. p. 345-348. In: 11th Conference on Biometeorology and Aerobiology, March 7-11, 1994, San Diego: American Meteorological Society.

Taha, H., 1996: **Modeling Impacts of Increased Urban Vegetation on Ozone Air Quality in the South Coast Air Basin**. Atmospheric Environment. 30, 3423-3430.

Taha, H., 1997: **Modeling the Impacts of Large-scale Albedo Changes on Ozone Air Quality in the South Coast Air Basin**. Atmospheric Environment. 31, 1667-1676.

Wong, T.W., 1996: **Parking Lot Shade Study: A Critical Examination of Davis Parking Lot Tree Shade**. Thesis. Department of Environmental Design, University of California, Davis.

***Present Address: California Air Resources Board, P.O. Box 2815, Sacramento, California 95812**

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