COOLING IMPACT OF URBAN TREES

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Background

Human activities, over the past two million years, have drastically modified the environment. They cleared the large areas of forest, grass land and created new landscapes. Humans started replacing the vegetated landscape with constructed citiescapes. Several physical features of the landscape combine to produce local climate variations. Chief among these are the influences of topography, proximity to the ocean, and urbanization.

Urban areas present distinctive microclimates. In the study of causes of the special climate in cities, Geiger (1966) reported "the total transformation of natural landscape into houses, streets, squares, great public buildings, skyscrapers, and industrial installations has brought about changes in climate in the region of large cities."

Temperature is one of the most important characteristics of urban areas. It is known that urban temperatures differ from those of suburban and rural surroundings. On hot summer days, one can feel the waves of blistering heat emanating from roads and dark buildings, which keep urban areas hot, even long after the sun has set, while the rural areas have already begun to cool rapidly. Depending upon topography, geographical location, and anthropogenic factors, urban areas are usually hotter than their rural surroundings. This phenomenon is described as the "urban heat island." A study by Akbari and others (1992), reported that urban temperatures are usually between 2° and 8°F hotter than their surrounding rural areas; for example, temperatures in New York City can be 10°F hotter than outlying areas. However, heat islands do not always encompass an entire city. They can develop over small areas, and sometimes even around single buildings. In a study of night time heat islands in San Francisco, Taha and others (1990) reported that the temperature differences has been found to be as large as 4°C along a street segment only one Km long. On a smaller scale, it has been shown that temperature deviations of this magnitude can be found on vegetation canopy just a few meters from the upwind edge (Taha et. al., 1990). Heat islands appear to be increasing in magnitude because of accelerated urbanization, deforestation, and the injection of anthropogenic heat and pollutants into the atmosphere. Since the early 1990's, the summer temperatures in most large cities in the U.S. have increased by 2-3°C (Taha et. al., 1990).

The urban heat islands have major effects on energy costs and the quality of urban life. It has been estimated that the heat island effect is responsible for 5-10% of the current urban electricity demand during the summer in the cities of the U.S (Sailor et. al., 1992). The power use for air conditioning rises with each degree increase in temperature. The consequent increased use of electricity for cooling elevates the levels of atmospheric CO_2 through the rising use of fossil fuels for electricity generation.

The earth's rising temperature is one of the most debated issues in the world today. The planetary temperature has been on the rise since the industrial revolution. Today, increased energy use is one of the main contributors to rising levels of atmospheric CO_2. According to the theory of global warming, the increased concentration of CO_2, the major "greenhouse gas", is one of the main factors responsible for raising the planet's average temperature (Balling, 1992). Excessive global warming can lead to as yet uncertain, but potentially catastrophic environmental consequences.

Vegetation has a large impact on micro-climates and is considered an efficient mechanism for cooling communities (Akbari et. al., 1989). In a study of the beneficial effects of climate, Geiger (1966) reported "wooded regions have a milder temperature, more similar to a maritime climate, than areas without forests." A lower concentration of vegetation results in conversion of a higher portion of the net solar gains into sensible heat, thus magnifying the heat island effect. In many areas, the loss of vegetation in urban areas is an important factor contributing to urban heat islands. Rural areas, as compared to urban areas, grow more trees, which generate a significant cooling effect on the atmosphere by the process of evapotranspiration. Similarly in cities, neighborhoods with more trees are cooler than those with fewer trees. Downtown areas of cities typically have the hottest temperatures, as they are dominated by tall concrete buildings and rarely support much vegetation.

Researchers have demonstrated that tree planting in cities could save as much as 34%, 18%, and 44% of residential cooling demand on a hot summer day in the U.S. cities of Sacramento, Phoenix, and Los Angeles, respectively (Akbari et. al., 1987). An annual 4-8% total energy savings can be expected from a well-placed 25 ft deciduous tree near an air-conditioned home (McPherson et. al., 1993). Models constructed for Sacramento, CA; Phoenix, AZ; and Lake Charles, LA, indicated that three trees per house could save approximately 30% of total annual energy used to air condition a house (Huang et. al., 1987). These findings are consistent with the results of a previous study by Parker (1983) which also reported a significant positive effect of trees around a building on its demand for energy for air conditioning during peak hours. In that study, it was found that peak power demands due to air conditioning could be reduced by about five kilowatts. In a study of planting for energy conservation, Sand (1991) reported that: "As much as 70 to 80 percent of the energy conservation benefit of trees may be attributed to reduction in urban heat island effects through the evapotranspiration effects of trees."

Therefore, vegetation is considered as one of the simplest and most effective ways to cool our communities and to save energy. It helps in protecting buildings against the scorching heat of sun in summer, and from cold winds in winter. Besides the cooling effect, vegetation also improves the urban environment by reducing noise pollution and soil erosion.

OBJECTIVE:

The objective of this study is to investigate the relationship between urban microclimate and local density of tree cover in order to estimate the cooling effects of urban trees. This was accomplished through a review and analysis of relevant meteorological data for daylight hours during the month of August for five years.

HYPOTHESIS:

Relationships between average ambient air temperature and percent tree cover were explored to investigate the hypothesis: "With an increasing percentage of local tree cover, there will be a corresponding reduction in average urban temperatures, all other factors being equal."

DATA COLLECTION:

The data for this study were collected by the Southern California Edison Company throughout its service territory over a five year period (1987-91) from 23 weather stations in Southern California. This study relied on measurements taken at 15 minute intervals for some data categories, such as ambient air temperature, and hourly or daily for other climatological parameters.

The month of August was chosen for this analysis because it is the hottest month, on average, in southern California. During this time, there is a peak load demand for electricity for air-conditioning and other cooling purposes. Also, the cooling effects of tree cover would be at its maximum during this hottest period of the year, and would therefore be most easily detected. In addition, from a policy-making perspective, increased tree cover would be helpful in reducing maximum peak loads for electricity use. As a result, there would be less excess power generation capacity standing unused during the rest of the year. For the month of august the daytime data were selected to achieve the objective of this study, because at that time the physiological processes of trees are active. It is also the time when energy consumption load for air-conditioning is at its maximum.

The weather stations used in this study spanned a variety of geographical and topographical conditions, but were identified as inland or coastal. This study attempted to isolate and eliminate the effects that sea breeze may have on inland weather stations, in order to calculate ambient air temperature average free of potential sea breeze effects. This study compared mean ambient air temperatures among inland weather stations surrounded by different percentage of tree cover (as measured by applying a dot grid to aerial photographs).

METHODS AND PROCEDURES:

Data used:

Fifteen minute average data for ambient air temperature, dew point temperature, wind speed, wind direction, and daily minimum and maximum ambient air temperatures from 22 weather stations, were considered for this study. However, detailed data analysis was conducted on only four of these stations, three were inland and one was a coastal weather station. The three inland weather stations were chosen on the basis of similar topography and geographical locations.

Data analysis:

The weather stations were identified as of two types, based on location: inland and coastal. Sea breezes influence microclimate, because they tend to reduce temperature by replacing dry hot air with cooler moist air.

Elimination of sea breeze effects: To isolate the cooling impact of urban trees, it was imperative that inland weather stations should be free of confounding sea breeze effects.

First, relationships among the temperatures at inland and coastal weather stations and also among the inland weather stations were identified. The locations of the 22 weather stations represented by the available data were used to identify those data suitable for this analysis. Daily maximum and minimum temperatures were analyzed via: 1) scatter plots with linear fits; and 2) time series plots* **

Unfortunately, dew point temperatures of coastal weather station were obtained for only three years in the available data sets, so hourly data were analyzed for the month of August for only three years i.e. 1987, 1989, and 1990. Four climatological parameters were considered: ambient air temperature, dew point temperature, windspeed, and wind direction. Regression analyses, descriptive statistics, and F, and t-tests[2] were used to assess the relationships among the three chosen inland and one coastal weather stations. Frequency plots of the number of observations against time and calculated time of sunrise and sunse*** were used to further segregate the data into subsets for day and night.

* Statistical analysis was conducted using the Statistical Analysis System (SAS Institute Inc.) program.

** A spread sheet program, Microsoft Excel, was used.

*** A spread sheet program, developed by Dr. Fred V. Nurnberger, State Climatologist, Mich. Dept. of Agriculture/Environmental Division.

On the basis of similar geographical location and topography, three inland weather stations (ST 11, ST 5, and ST 15) were chosen for analysis. These inland weather stations were located 22, 28, and 50 miles from the coast, respectively. One (ST 7) was a coastal weather station. Location of these weather stations is presented in Table 1. Station 11 was surrounded by residential areas. A large golf course was situated on the NW side of the weather station. Station 5 was surrounded by residential areas and small patches (mostly in the NW and NE quadrants) of barren and grassy lands. Mountains, partially covered with trees, were situated in the SE and SW quadrants of weather station 5. Station 15 was also surrounded by residential areas and scattered grassy and barren lands, especially on the SE side of the weather station. Station 7 was a coastal weather station. The Pacific ocean occupied the NW and SW quadrants, while in the NE and SE quadrants, industrial and residential areas were situated.

Table 1. Location of weather stations used in the analysis.

Station	Site	Coastal Distance (miles)	Thomas guide #	Country
Inglewood	St7	00.09	732-D1	Los Angeles
Montebello	ST 11	22.00	596-G5	Los Angeles
Covina	ST 5	28.00	600-A3	Los Angeles
San Bernardino	ST 15	50.00	15-E3	San Bernardino

Regression analysis was used to calculate the percent variability in the dew point temperatures of inland weather stations related to sea breeze effects. This statistical analysis was run between the values of dew point temperatures at coastal and inland weather stations. To exclude data affected by sea breezes, the data from the inland weather stations were divided into four different sectors of varying size by wind direction. The construction of the sectors was based on their orientation and average distance from the coast in order to segregate sea breeze influenced zones. For example, ST11 was divide into four sectors by wind direction in degrees. These sectors were: sector 1 (170-200°; sector 2 (200-225°); sector 3 (225-260°); and sector 4 (260-170°). Accordingly, four new data files were created for each month of August for each inland weather station, and each sector was evaluated separately. Wind direction at the coastal weather station was also used to reshape the data into sea-breeze and land-breeze by dividing the coastal weather station into two sectors.

The travel time of wind from the coast to reach the inland weather stations in each sector was calculated. The adjusted time or lag time was determined by subtracting the travel time from the actual time in that sector. With the help of the lag time, the lagged dew-point temperature was selected for each sector at each weather station for the month of August for each of the three years, individually.

The lagged dew point temperature is the temperature at a coastal weather station determined by taking the corresponding dew point temperature at the inland weather station at an adjusted time equal to the lag travel time from the coast to the inland weather station, based on the windspeed and direction at the inland weather station. Basically, it is the wind which reaches the inland weather station after travelling the distance from the coast in wind direction at that time. In other words, it indicates the relationship between dew-point temperatures at the coastal and inland weather stations.

The differences between the lagged and actual dew-point temperatures were calculated. Descriptive statistics (at 95% confidence level for mean) were used to compute mean, variance, and standard deviation of the differences between the lagged and actual dew-point temperatures for each of the three inland weather stations for each of the months of August, separately. The values which were more than one standard deviation from the mean were kept as non-sea breeze hours for further analysis. The rest of the values were eliminated because they were considered likely to represent coastal winds. Regression analysis was run again (at 95% confidence level) between the values of actual and lagged dew-point temperatures which were more than one standard deviation from the mean. Those values of actual dew-point temperature less than one standard deviation were discarded, as representing sea breeze.

F-tests comparing the variances of ambient-air temperature measurements from the coastal and inland weather stations were conducted to determine the appropriate procedure to use for comparison off means. A t-test ($\underline{x} = 0.05$), using either equal or unequal variances depending on the result of the F-test, was used to compare the means of ambient air temperature measured at the coastal station with each of the inland weather stations. Three pairwise t-tests were used to compare the means of ambient air temperatures for all the three inland weather stations for the month of August for three years.

Daily mean temperature range: To explain the lack of difference between weather stations which have different percentages of tree cover, but had statistically similar average ambient air temperature, the data were further analyzed to calculate the daily mean temperature range at all the weather stations. For this purpose, maximum and minimum ambient air temperatures were taken into consideration for the three August months for the inland and coastal weather stations. The average temperature range for each station was calculated as the mean of daily temperature ranges (daily maximum temperature - daily minimum temperature) for all the three August months. Average maximum and minimum temperatures were also calculated for each station.

Isolation of day-night effects: In order to analyze the data more precisely and to achieve the objective of this study, the area of each inland weather station was divided into four equal quadrants (NE, SE, SW, and NW) based on wind direction, and a separate data file was created for each quadrant for each inland weather station. For each quadrant, average wind speed, mean time of observations, average ambient air temperature, and percent of the time the wind was coming from that quadrant, were calculated. The percent of the time that the wind was coming from each quadrant was calculated by dividing the total number of observations in that quadrant by the total number of observations taken.

The descriptive statistics of the hourly time were calculated for all four quadrants of each of the inland weather stations to determine whether the temperature of the wind from a given direction tended to be for night or day. The sunrise and sunset time for each weather station was calculated for August Ist, 15th, and 31st at the given latitude and longitude of each of the inland stations to separate observations into day and night.

Frequency plots for each quadrant for each weather station were also drawn to identify the trends in data with respect to time. Observations which were representing time between sunrise and sunset were kept for further analysis. For each inland weather station, average ambient air and maximum temperatures were calculated from the hourly data in those quadrants representing day time (between sunrise and sunset). Finally, an F-test was used to compare the variances of ambient-air and maximum temperatures of inland weather stations (only those quadrants representing day time data). On the basis of results from the F-test, the appropriate t-test ($\underline{x}$ = 0.05) was used to compare the means of ambient-air temperatures and the means of maximum temperatures of inland weather stations for the month of August for three years.

Characteristics of tree cover:

In order to characterize the tree cover around the weather stations, a dot grid method was used as described by Spurr (1948), and Lillesand and Kiefer (1987). Aerial photographs with a scale 40,000 to 1 of the relevant neighborhoods* were obtained. A dot grid (40 dots/sq. mi.) was superimposed on the photographs. Percent tree canopy was measured by counting the number off dots falling on trees. Dots that overlapped more than 50% were counted as a full cell. Where they were marginal, two cells that were 50% were counted as one cell toward the calculation of percentage. Dots that were obviously less than 50% were not counted. The number of grid cells overlapping the tree canopy were then divided by the total number of possible grid cells in the region of interest and multiplied by one hundred. The resulting value indicated the percent tree cover in the area.

For each quadrant, tree cover was measured to a redius of two miles from the weather station. the total (four quadrants combined) tree cover ranged from 3% to 56% (Table 2), while for individual quadrants the range was from 0% to 58% (Table 2). The stated purpose of this study was to isolate the effects of tree cover on temperature.

* Aerial photographs obtained from the U.S. Department of Agriculture (Agriculture Stabilization and Conservation Service Aerial Photography Field Office 2222 West, 2300 South- P.O. Box 30010. Salt Lake City, Utah 84130

Table 2. Total Percent Tree Cover within a Two Mile Radius and within four quadrants (two mile radius) of each weather station.

	Coastal Weather Station	Inland Weather Stations		
Station	ST 7	ST 11	ST 5	ST 15
NE	3%	58%	41%	30%
SE	9%	57%	58%	21%
SW	0%	55%	54%	47%
NW	0%	54%	34%	58%
Total % Tree Cover	3.0%	56.0%	46.8%	39%

RESULTS:

In the analysis of the implication of local tree cover on temperature, it was found that lower temperature is consistent with higher percentage of tree cover. Between the weather stations, having a difference of 8% tree cover, there was a difference of 3°F in the average ambient air and 7°F in the maximum temperatures in the SW quadrant (Table 3). A study done by Akbari (1990) showed that trees can reduce peak day time temperature by 4°F to 6°F but it does not specify the difference in percent tree cover, because that study only compared an unspecified amount of forested area to another without trees. It may be conclude that the results obtained from this study are consistent with the hypothesis that "with an increasing percentage of a local tree cover, there will be a corresponding reduction in average urban temperature, all other factors being equal.

Table 3. Results for the southwest quadrant of the day time data for August months for three years *1987, 89, and 90) all three inland weather stations.

	Percent Tree cover	Mean ambient Air Temp (°F)	Maximum Temp (°F)
ST 11	55	77.10a[1]	82.09a
ST 5	54	77.42a	82.10a
ST 15	47	80.98b	89.06b

1. Values followed by same letter (in same column) are not significantly different (p-0.5; two-tailed t-test).

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