4. CHICAGO AREA CASE STUDY

Through the manipulation of the ratios between the percentage of vegetative cover and high and low albedo surfaces, it may be possible to substantially reduce urban heat island effects. For example, research at the Lawrence Berkeley National Laboratory (LBNL) has examined these effects in simulations of the cooling achieved by increasing the albedo of roofs and roadways in the LA Basin. Researchers showed that a 4°F cooling was obtained by noon, which in turn resulted in a 10-12% population based reduction in smog exceedances.(46)

As shown previously in *Table 2* (page 16), Los Angeles is the only area in the extreme classification for ozone nonattainment. Chicago is among the cities classified as severe ozone nonattainment areas, which serves as the impetus for this study evaluating the estimated effects of cooling strategies to abate the urban heat island effect and ozone problem in Chicago.

In this chapter, the heat island and ozone exceedance distribution of the immediate Chicago area are located geographically. The relationship between temperature and ozone is examined in order to obtain an understanding of the regional features associated with the observed ozone exceedance distribution. Finally, an urban fabric analysis is conducted for the city of Chicago as an initial step in the investigation of how increased vegetative cover and the use of cooler roof and pavement materials may help decrease the effects of the urban heat island

4.1. TRENDS IN METROPOLITAN CHICAGO

4.1.1. Monitoring Stations

Ozone is generally monitored only between the months of April and October, the so-called ozone season. Several Chicago monitoring stations may collect data over a longer period of the year, but since ozone levels are much lower during the winter months, this project utilizes only the summer ozone data (April – October).

Ozone concentration data for the Chicago area were obtained from the Aerometric Information Retrieval System (AIRS). This system is a database of air quality monitoring site data from local, regional, and national monitoring stations throughout the United States. Unfortunately, the AIRS database has two major shortcomings. First, complete station data records are not always available. For example, although the AIRS database contained pollutant data for 23 stations in the Chicago area, only 17 stations collected ozone data. Second, different monitoring locations have varying collection periods. As a result, hourly ozone concentrations were collected from only 13, of the total 17, different monitoring stations throughout the Chicago region for the longest, most current and complete time frame available, 1992-1996. From these data, the daily maximum concentrations were extracted and analyzed. *Figure 33* shows the coordinates and locations of these sites that monitored ozone.

Figure 33: Ozone Monitoring Stations in the Chicago Region

Station Location	**ID**	**Latitude (N)**	**Longitude (W)**
Alsip	A	41°40′	87°43.5′
Chicago (Lakefront)	B	41°45′	87°32.5′
Stony Island	C	41°42′	87°34′
Lincolnwood	D	41°59′	87°47′
Lemont	E	41°40′	87°59′
Cicero	F	41°51′	87°45′
Evanston	G	41°63.5′	87°40′
Wrigleyville	H	41°58.5′	87°40′
Chicago (Downtown)	I	41°52.5′	87°38′
University of Chicago	J	41°47′	87°36′
Lisle	K	41°49′	88°04′
Deerfield	L	42°10.5′	87°50′
Elgin	M	42°03′	88°16′

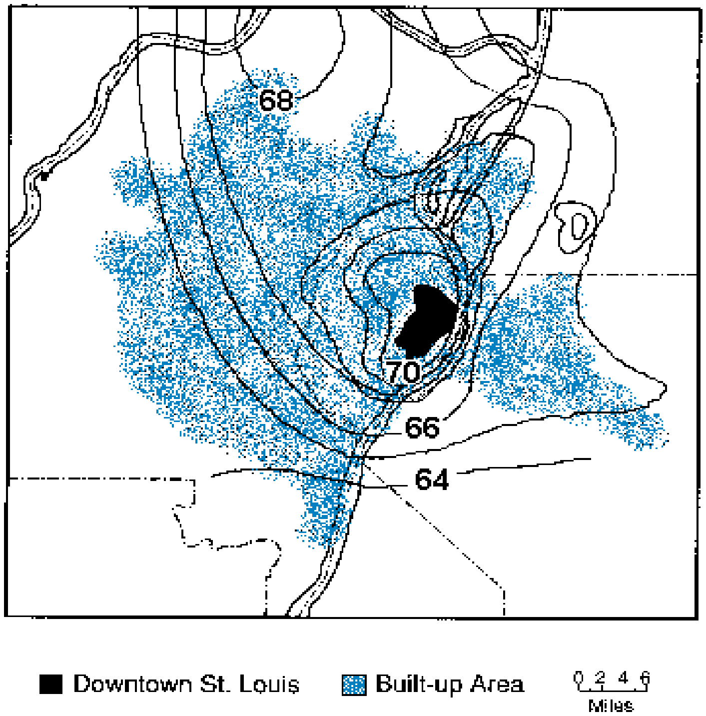
Figure 33 (continued)

Source: *Microsoft Expedia Streets98*

4.1.2 Temperature and Ozone Trends

The definition of "heat island" is an area with heightened air temperatures of 2-8°F, increased energy demands, and elevated pollution concentrations as compared to the surrounding areas. This phenomenon is illustrated for St. Louis in *Figure 34.*

Figure 34: Heat Island Profile for St. Louis, Missouri

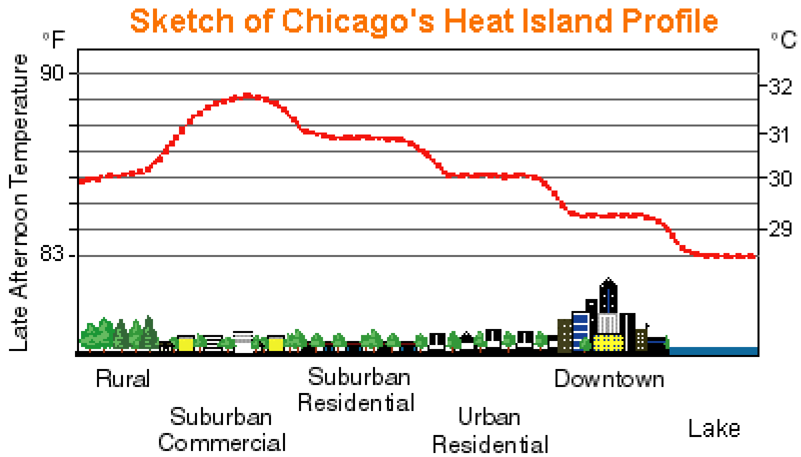


Source: Cool Communities (3)

The temperature profile of a heat island can vary significantly throughout an area. In order to identify the location of the Chicago heat island, data for the daily maximum temperature were obtained from the National Climate Data Center (NCDC). These data were collected for locations in the Chicago area that corresponded to the ozone monitoring stations (*Figure 33*) so that the relationship between ozone and temperature could be evaluated.

In contrast to St. Louis, when the average temperature distribution in the summer months (June-August) for the 1992-1996 time frame, is analyzed for the Chicago Area, the actual Chicago Heat Island consistently appears in the western suburbs, not in the Downtown area. In this case, the climate of Downtown Chicago is influenced to a great extent by Lake Michigan, which results in a suburban heat island centered on an area of rapid suburban development. This is illustrated in *Figure 35*. More specifically, as shown in *Figure 36*, there is on average about a 3-5°F temperature gradient between Lisle and Downtown Chicago.

Figure 35



An examination of the ozone data for the Chicago Area, specifically Cook County, revealed that the majority of the ozone noncompliance days do not occur in Downtown Chicago. Instead, they appear to center around the northern suburbs, specifically Evanston. *Figure 37* shows a surface plot of the total number of days where ozone levels exceeded 120 ppb as a function of their geographical location around Chicago.

In order to verify that the location of the Chicago heat island did not coincide with the local region of greatest ozone noncompliance, *Figure 38* was generated. This figure shows a histogram of the daily temperature difference found at the center of the heat island (Lisle) and in the area of greatest ozone noncompliance (Evanston). From examination of these data, it is observed that the temperature in Lisle is almost always higher. The few days where the temperature in Evanston was found to be higher occurred mostly on days in the early spring (April/May) or early fall (September/October). Furthermore, if one examines this temperature difference on each of the six days of ozone noncompliance in Evanston, it is also found that the temperature was almost always greater in Lisle. The one exception occurred on a day in mid July of 1995 when the temperature in Lisle was 99°F and the temperature in Evanston was 102°F.

Figure 36: Summer Heat Island Profile for the Chicago Area

Maximum daily temperatures averaged over the ozone season

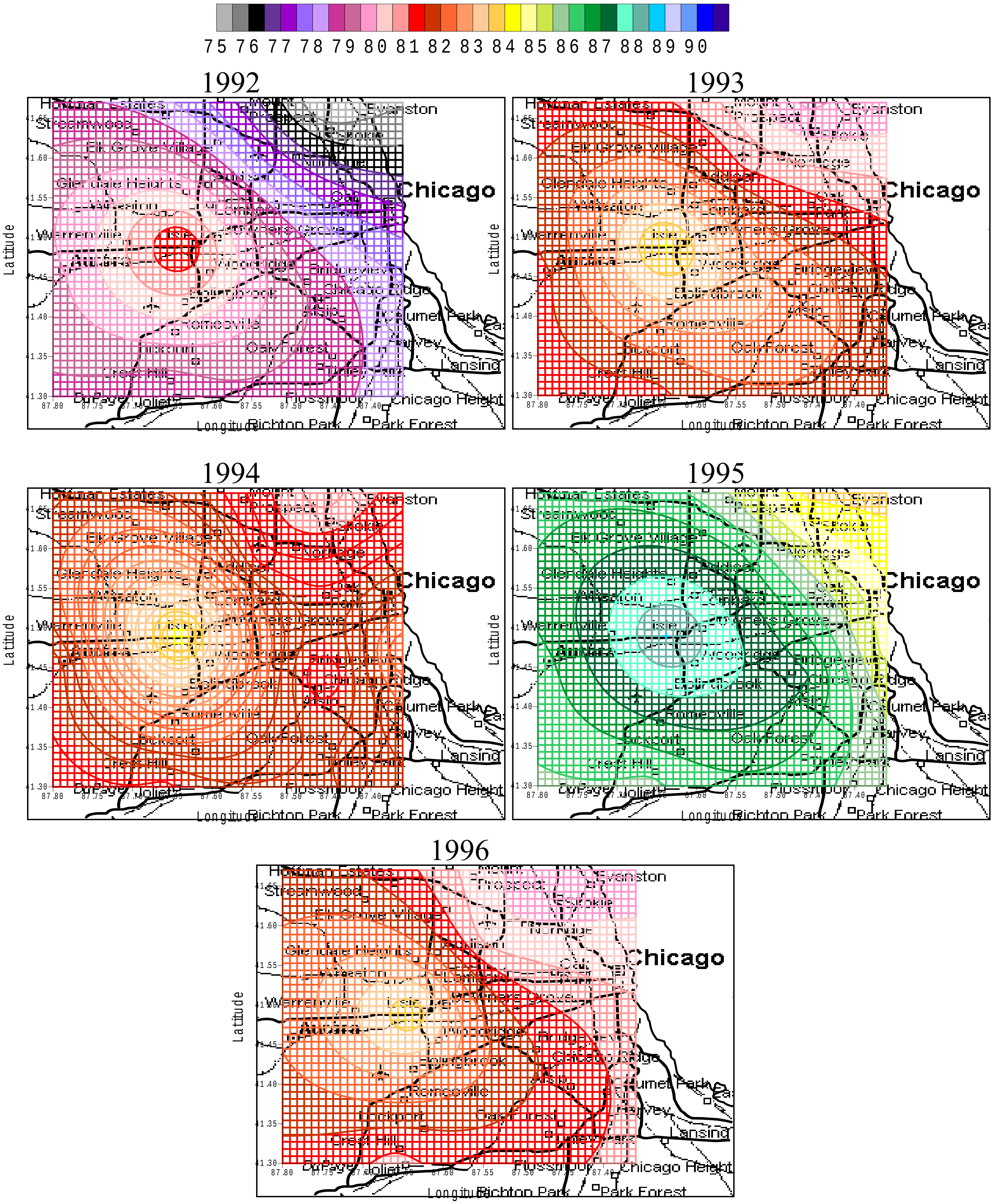


Figure 37: Ozone Noncompliance Distribution for the Chicago Region for April – October 1992 to 1996

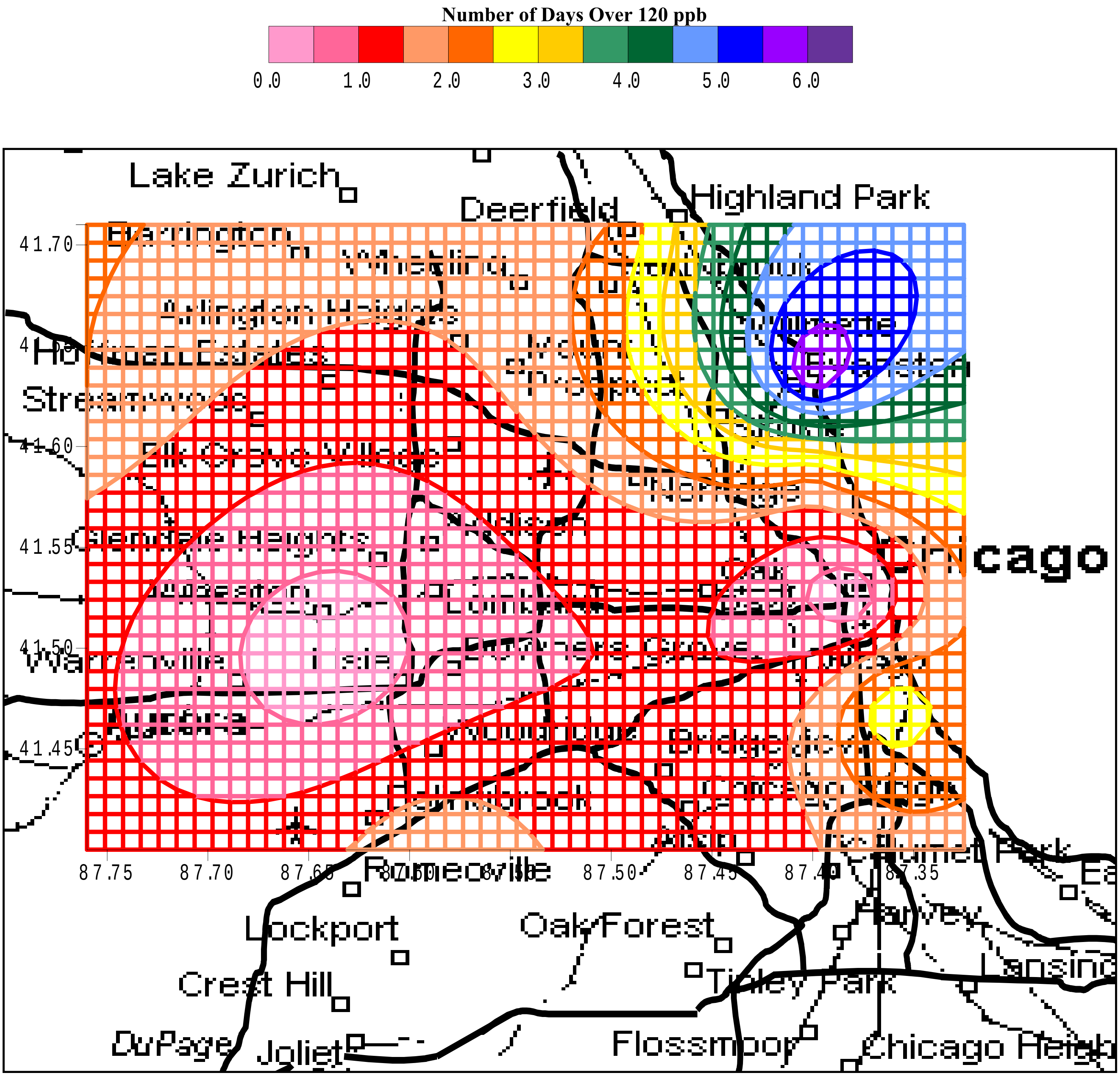
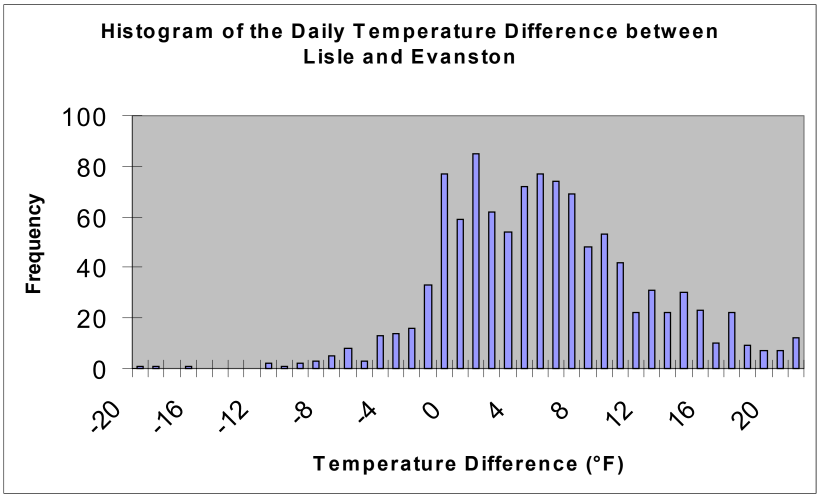


Figure 38



In summary, it is observed that the ozone noncompliance distribution does not coincide with the heat island and is over an area with few known emissions sources. The result of this comparison supports the hypothesis that atmospheric and surface transport mechanisms greatly influence the ozone distribution in the Chicago area, as discussed in section 2.3.2 (page 23). This conclusion is reinforced by the fact that, during the summer ozone season, the Chicago Area is frequently ventilated by prevailing northeasterly transport winds, illustrated previously in Figure 9, which assist in the redistribution of high ozone concentrations to areas with little to no emissions sources. This phenomenon, in association with other research conducted within this area (15,17,28), supports the idea that ozone exceedance is a regional issue. The movement of air masses facilitates the transfer of O_3 and its precursors beyond their originating sources to adjacent areas creating episodes of high O_3 in locations that have few emissions. As shown in Figure 6, while Chicago may serve as an emissions source, the actual ozone exceedances often occur in western Michigan and eastern Wisconsin.

In general, all the noncompliance days in the Chicago Region occur in the deep summer months (June-August) and at relatively high temperatures. It was observed that during this five year time interval (1992-1996), approximately 70% of the ozone exceedances occurred on days having temperatures above 85°F, approximately 90% of the exceedances were observed at temperatures above 80°F, and there were no exceedances observed below 77°F. A summary of the Chicago area noncompliance data is located in *Table 8*, which shows the location of each monitoring station, the date of ozone exceedance, the maximum daily temperature corresponding to the location and date of each exceedance, and the recorded ozone concentration level corresponding to every episode.

Table 8: Ozone Noncompliance Summary for the Chicago Area

Data Station Location	Date	**Maximum Temperature (°F)**	**Maximum Ozone Concentration (ppb)**
Suburb - North (Deerfield)	07/01/92	78	127
	06/16/94	98	126
Suburb - North (Evanston)	6/13/92	83	121.3
	7/1/92	78	129.3
	8/9/92	84	135.3
	7/15/95	102	149.3
	8/12/95	93	140.3
	6/27/96	81	122.3
City - North (Wrigleyville)	7/15/95	103	121.3
	6/28/96	94	125.3
Suburb - Northwest (Elgin)	06/13/92	86	128
	06/18/94	96	127
City - Northwest (Lincolnwood)	7/1/92	91	121.3
	6/24/95	94	124.3
Suburb - West (Lisle)	N/A	N/A	N/A
City - West (Cicero)	7/1/92	88	121.3
City – Downtown	N/A	N/A	N/A
City - Southwest (Alsip)	7/13/95	106	129.3
City - South (U of C)	7/1/92	82	133.3
	6/24/95	88	134.3
	7/13/95	96	130.3
City - South (Lakefront)	6/27/95	79	127.3
	6/27/96	82	127.3
City - South (Stony Island)	6/24/95	88	166.3
	7/13/95	96	126.3
Suburb - Southwest (Lemont)	6/13/92	91	131.3
	6/18/94	95	169.3

The relationship between ozone and temperature levels for the ozone noncompliance days in Chicago is further illustrated in *Figures 39* and *40*. *Figure 38* is a graphical representation of the maximum ozone concentration and temperature data presented in *Table 8*, and illustrates once again, the absence of a positive linear relationship between temperature and ozone. The frequency of ozone episodes occurring in a particular temperature range relative to the total number of days observed in that temperature range is shown in *Figure 40*. The data in this chart represent values collected throughout the Chicago area during the 1992-1996 ozone seasons. The numbers above each bar depicts the total number of days that fell in that temperature range.

Figure 39: Ozone Noncompliance Distribution for the Chicago Area

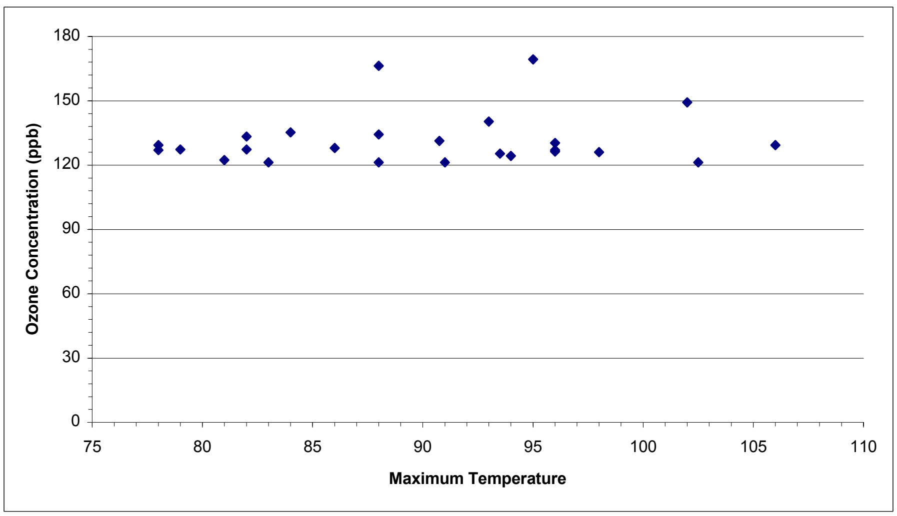
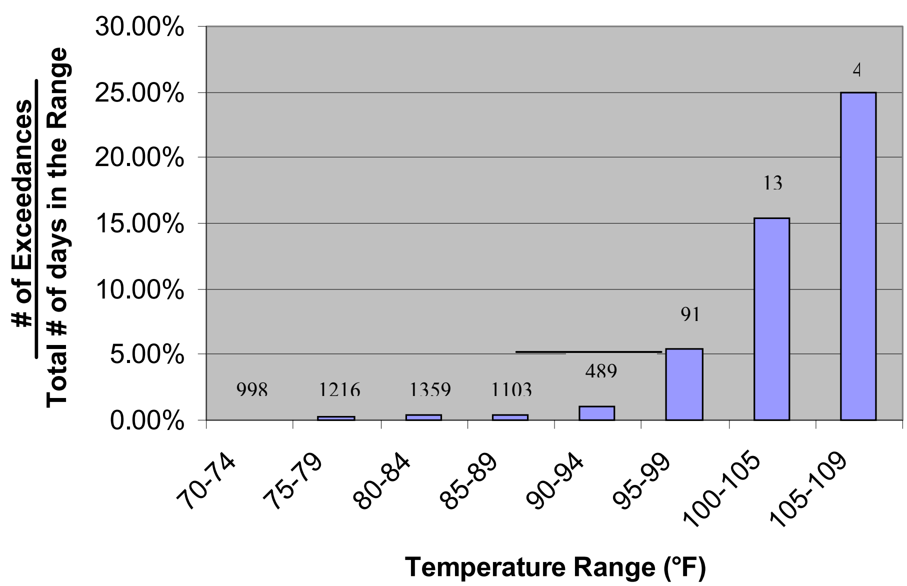


Figure 40: Frequency of Ozone Episodes in a Specific Temperature Range Relative to the Total Number of Days in that Range



These data illustrate that despite the very weak direct relationship found between temperature and ozone concentration in Chicago (*Figures 11* and *39*), there is a temperature threshold below which ozone exceedances are less likely to occur. Over the time interval of these monitoring data, no ozone exceedances were observed at temperatures below 77°F and the majority of the ozone exceedances occurred at temperatures above 80°F. Yet, for all the monitoring stations studied in the Chicago area, relatively few days in the temperature range of 80-95°F, range relative to the total number of days registering that temperature, experience smog events, typically 1% or less.

The trend shown in *Figure 40* illustrates that at extreme temperatures, above 95°F, the likelihood of ozone exceedances increases with temperature. The data reveal that the number of ozone exceedances relative to the total number of days in the 95-99°F temperature range jumps to 5% and then continues to increase as temperature increases. *Figure 40* also shows that, although a very high frequency of occurrence (25%) was observed in the 105-109°F temperature range, the total number of temperature observations was very low. Finally, these data suggest that there is a temperature threshold of 95°F to more frequent occurrence of ozone exceedances. Thus, in Chicago, while higher temperatures do not promote higher ozone concentrations, very high temperatures (95°F and above) do show a greater proportion of smog events relative to the total number of days in the same high range.

4.1.3 Implications for Chicago

There are various ways of combating the urban heat island. If properly applied, these strategies, discussed in detail in the next section, can help reduce the temperature, energy demand, and pollutant level within a city. For example, simulations of the cooling achieved through the replacement of dark roofs and roadways with alternate “cooler” materials were done for the Los Angeles Basin. The results showed a 4°F cooling by noon and a 10-12% reduction of smog exceedance.(47)

The use of cooling strategies if applied to the metropolitan Chicago area may produce a decrease in temperature, similar to that predicted for the LA Basin. However, ozone noncompliance days are not solely the result of temperature effects, particularly those that occurred in the city of Chicago. Instead, the Chicago area is greatly affected by a combination of various meteorological processes that together are responsible for transporting polluted air into (and out of) the region. These phenomena have been documented by the Ozone Transport Assessment Group (OTAG) (17) and Lake Michigan Ozone Study (LMOS) (28).

Of the eight noncompliance days from 1992-1996 that occurred at temperatures below 85°F, only three exceedance measurements were made in the city limits of Chicago (at two sites - the University of Chicago and Southern Lakefront). The other five ozone exceedances occurring at temperatures below 85°F were measured in the Northern Suburbs of Chicago (Evanston and Deerfield). At all of the aforementioned locations, it is likely that factors other than temperature are at play, although it can be assumed that that a portion of the ozone originates from within the domain as a result of the reactions of O_3 precursors.

Based on the simulations for the LA Basin, a 4°F decrease in temperature may also produce a 10-12% reduction of the smog events in the Chicago area, eliminating the ozone episodes that occurred at temperatures below 80°F. For the Chicago area, this translates to eliminating approximately 3 exceedance episodes over a five year period.

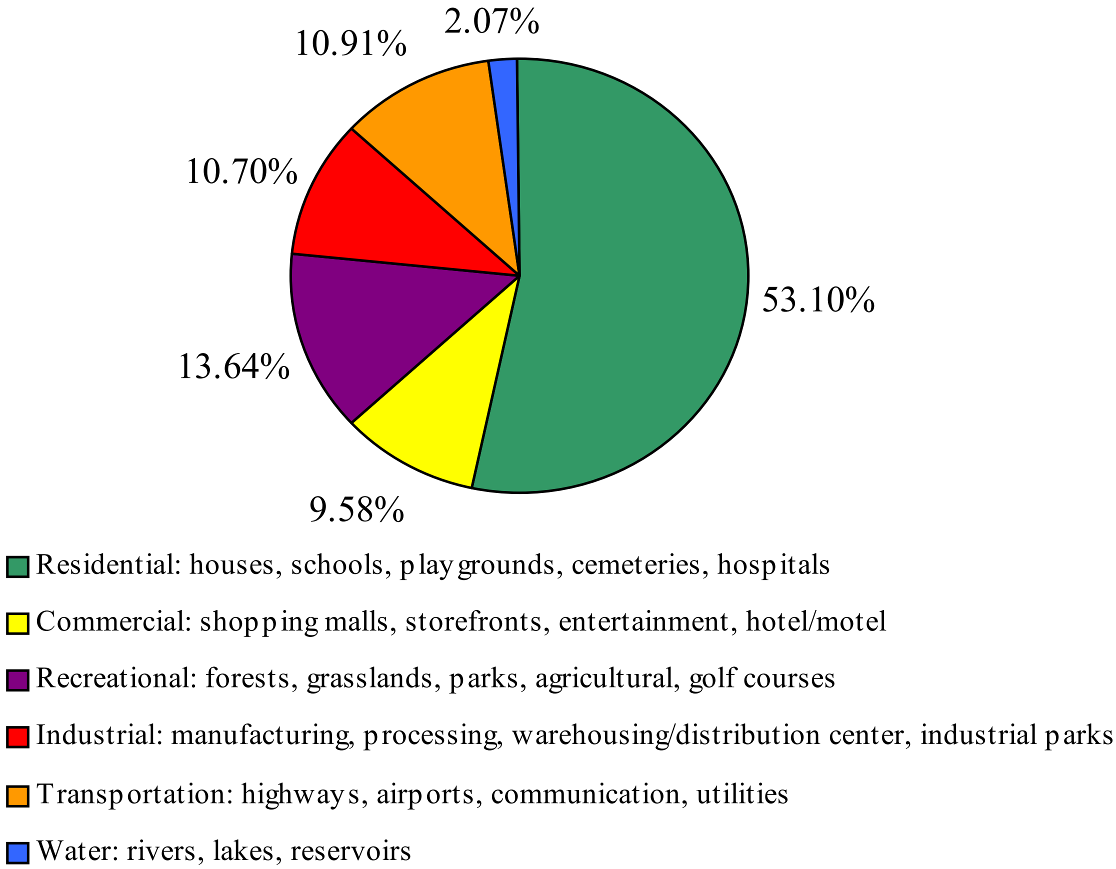
Since the reduction in the absolute number of ozone exceedances is small, it is important to stress the many other benefits cooling strategies promote. In addition to eliminating smog events, cooling strategies and decreased summer temperatures result in diminished energy use, fewer deleterious health effects, and an enhanced comfort level. These factors are likely to produce additional cascading benefits. Thus, simulations of cooling benefits should include these other outcomes, in addition to reductions in ozone exceedances.

4.2. URBAN FABRIC ANALYSIS

4.2.1. Land Use

An urban fabric analysis determines the proportions of vegetative, roofed, and paved surface cover relative to the total urban surface in the city. In order to accurately analyze the effect of surface cover modifications, attain pertinent results, and eventually simulate realistic estimates of temperature and ozone reductions resulting from these modifications in Chicago, the current urban fabric of the Chicago must be quantified as it relates to different land use. As a result, each land use category specified was analyzed according to the relative percentages of vegetative, roofed, and paved surfaces. *Figure 41* shows the classification and relative proportions of land use in the city of Chicago for 1990.(48) From this figure, it is observed that the largest section of land use is residential, at 53%; unfortunately, there were not sufficient data available to specifically distinguish between high, medium, and low density residential areas. The remaining sections, which include transportation, industrial, recreational, and commercial, are relatively equivalent and have an average cover of approximately 11.5%.

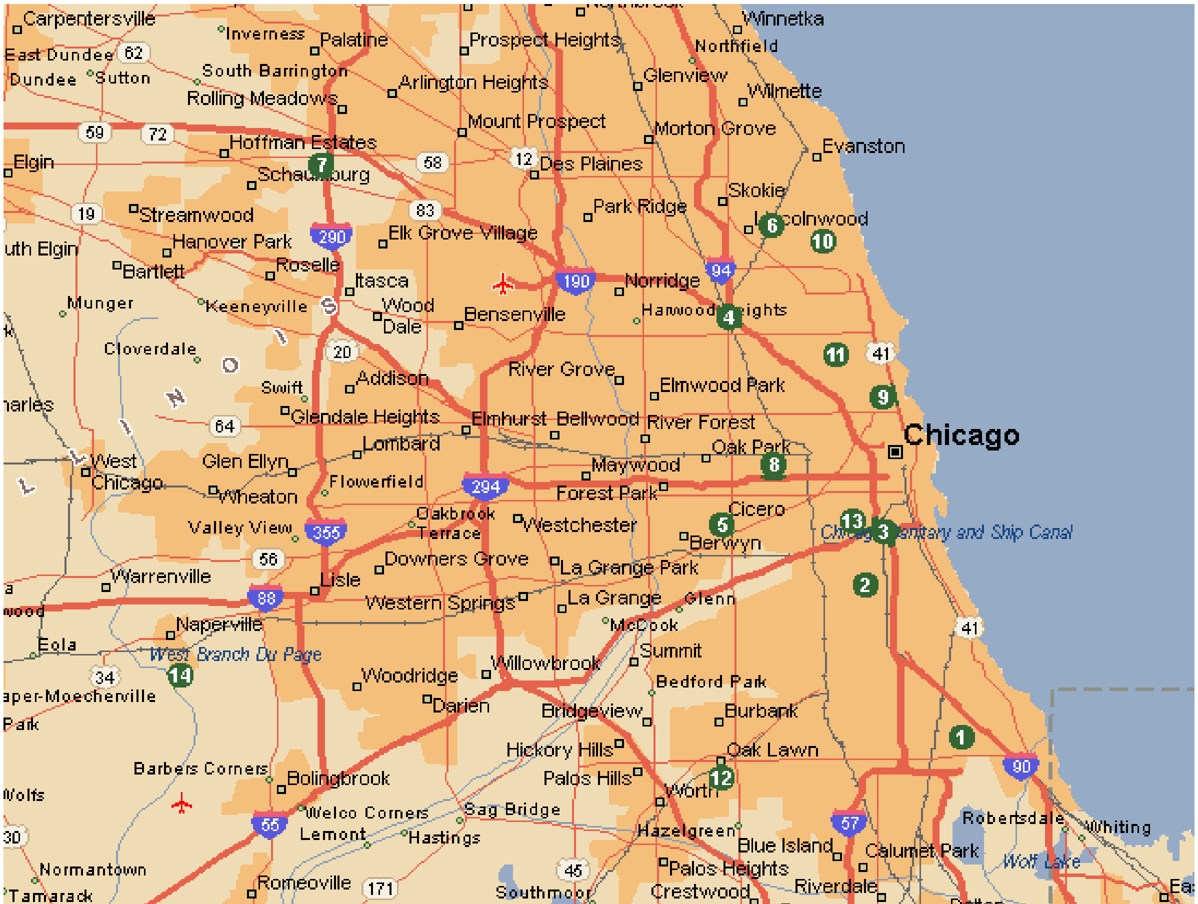
Figure 41: Land Use in the City of Chicago, 1990



4.2.2 Methodology

The urban fabric analysis of Chicago was completed through the examination of color digital aerial photographs (1 ft by 1 ft resolution) obtained from Image Scans Inc., Wheat Ridge, CO, during an October 1998 fly over. Because the city of Chicago covers over 225 one square miles, budget and time constraints made it impossible to analyze the entire Chicago area. Therefore, in order to obtain an accurate estimate of Chicago's urban fabric, fourteen distinct square mile sectors were selected to serve as a representative basis for the overall land use in the Chicago area. The locations of these areas are shown in *Figure 42* and given in Appendix D.

Figure 42: Urban Fabric Analysis Sector Locations



Sector #	Location Description	Land Use Categories
1	Stony Island - Burnside	residential, commercial
2	Stockyards – International Amphitheater	industrial
3	Interchange 55/90/94	transportation
4	Kennedy Interchange 90/94	residential, transportation, commercial
5	Cicero	residential, industrial
6	Lincolnwood	residential, commercial
7	Schaumburg – Woodfield Mall	commercial
8	Garfield Park	residential, recreational
9	Lincoln Park	residential, recreational
10	Rogers Park	residential, recreational
11	Wrigleyville	residential, commercial
12	Oak Lawn	residential
13	Blue Island – Pilsen	residential, industrial
14	Naperville	residential

In addition to representing the five basic land use categories, residential, commercial, recreational, industrial, and transportation, the 14 sample areas were selected to permit an assessment of variation based on location and density. As shown in *Figure 42*, the areas sampled included high, medium, and low density residential, urban and suburban commercial, and southern and western industrial. Furthermore, many of the 14 square mile sectors displayed mixed land uses, for example, residential neighborhoods surrounding recreational areas or industrial areas. Thus, the fourteen sections also included multiple samples for each land use category.

The fourteen sectors were chosen based upon our knowledge of Chicago and information from Northeastern Illinois Planning Commission (NIPC) land use maps. It was relatively simple to identify all of the land use categories, except for industrial, using a map of the Chicago area and our knowledge of its current urban layout. The NIPC information was used primarily to confirm our assumptions. The industrial areas within Chicago were located based on information and maps provided by the Chicago Department of Planning and Development (DPD).(47)

Analyzing the aerial photographs was an extremely complicated and time consuming process. It was initially intended that the entire analysis be performed using image analysis software developed by the Scion Corporation, Frederick, MD. This program allows objects to be segmented on the basis of color. However, due to the complex nature of the ground cover coloring, no consistent pattern between the various surfaces could be detected directly from the digital photographs. Thus, before applying the analysis software, it was necessary to visually and manually classify the distinctions between the land cover categories, vegetative, roofed and paved surfaces, for each land use category within every sector. This was accomplished using

Adobe Photoshop 4.0 to manually alter the digital photographs. First, two to four subsections were chosen for analysis within each land use category for each square mile area. Then each surface cover type was differentiated from the others using a single color, which was used as the basis for a density slice analysis of the total area. The results of these analyses were then utilized to calculate the overall percentages of vegetative, roofed and paved surfaces for each land use category in each sector.

4.3. RESULTS AND EVALUATION

The results of the urban fabric analysis are summarized in *Table 9* (a detailed synopsis is provided in Appendix E). In general, the percentages are reasonably consistent within the different areas of the city for same type of land use category, although in a few cases a relatively wide range was measured. The variations that arise are dependent upon the surface type being examined and the specific area of the city analyzed, for different areas are naturally diverse with respect to specific land cover. These variations are further explained in the 'Comments' column of *Table 9* and summarized in *Table 10*. For example, the paved surface range for the urban commercial areas varied about 30% from highest to lowest depending upon which area was specifically analyzed. In general, this percentage is dependent on the amount of area devoted to parking lots and decreases as one moves from southern to northern sections of the city. Unfortunately, it is extremely difficult to incorporate all these variations. As a result, an average value that can be applied to the city as a whole is utilized in this research for comparison and analysis purposes.

The residential category included the greatest number of samples, 12, and represented three different density regions within Chicago. The specific areas represented within the urban,

Table 9: Urban Fabric Analysis for the Chicago Area

CATEGORY	***VEGETATIVE AVERAGE***	***VEGETATIVE RANGE***	***ROOFED AVERAGE***	***ROOFED RANGE***	***PAVED AVERAGE***	***PAVED RANGE***	***# OF SAMPLES***	***COMMENTS***
Residential – Urban (Medium/High Density)	45.12 %	33.36 % - 55.00 %	34.42 %	26.05 % - 51.07 %	20.47 %	14.60 % - 28.02 %	12	These values vary depending upon which area of the city was analyzed. They include areas north, west, and south of the city.
Residential - Near Suburban (Medium/Low Density)	49.67 %	42.27 % - 57.80 %	27.17 %	21.36 % - 35.64 %	23.16 %	20.84 % - 25.32 %	4	These values vary depending upon which suburb was analyzed. They are representative of three near suburbs: Lincolnwood, Oak Lawn, & Cicero.
Residential – Far Suburban (Low Density)	70.51 %	64.86 % - 76.15 %	12.70 %	11.99 % - 13.42 %	16.79 %	11.86 % - 21.72 %	2	These values are representative of only one far suburb: Naperville.
Recreational	67.19 %	56.49 % - 79.82 %	6.66 %	2.82 % - 9.62 %	21.61 %	17.36 % - 26.70 %	4	The variation occurs because this category includes analysis of large parks, small parks, and schools with athletic fields.
Transportation	31.74 %	23.55 % - 40.77 %	0.00 %	0.00 %	68.26 %	59.23 % - 76.45 %	3	These values are based major highways running through downtown Chicago (i.e. 55, 90, & 94). This category does not include any developed areas surrounding the highways.
Commercial – Urban	16.10 %	11.79 % - 20.99 %	33.14 %	22.32 % - 46.95 %	50.77 %	32.07 % - 62.17	3	These values vary depending upon which area of the city was analyzed. They include areas north, west, and south of the city.
Commercial - Suburban	12.15 %	9.55 % - 17.33 %	26.24 %	17.88 % - 35.44 %	61.61 %	52.44 % - 72.58 %	4	These values vary depending upon which suburb was analyzed. They are representative of both a near and far suburb: Lincolnwood & Schaumburg.
Industrial	10.32%	1.71 % - 20.98 %	42.05 %	35.22 % - 50.20 %	47.63 %	43.80 % - 51.01 %	3	These values vary depending upon type of industrial category was present in the particular area analyzed. The variation occurs because this category includes the analysis of warehouses, stockyards, and industrial office complexes.

Table 10: Geographical Variations of the Urban Fabric within each Land Use Category

Category	***Location***	***Areas***	***Vegetative Surface***	***Total Roofed Surface***	***White/Light Roofed (% of total roof)***	***Total Paved Surface***	***Water***
Residential – Urban/Near Suburban (Low/Medium Density)	North	Rogers Park, Lincolnwood	44.06%	30.31%	40.35%	25.62%	x
	Central	90/94, Wrigleyville, Garfield Park, Lincoln Park, Cicero,	44.78%	36.90%	39.26%	18.32%	x
	South	Blue Island/Pilsen, Stony Island, Oaklawn	46.41%	29.80%	29.37%	23.78%	x
Recreational	North	Rogers Park	65.71%	9.62%	29.06%	24.67%	x
	Central	Garfield Park, Lincoln Park	67.68%	5.68%	33.47%	20.59%	9.08%
	South	x	x	x	x	x	x
Transportation – Highway Exchange (w/o surrounding area)	North	90/94	30.89%	0.00%	0.00%	69.11%	x
	Central	55/90/94	32.16%	0.00%	0.00%	67.84%	x
	South	x	x	x	x	x	x
Transportation - Highway Exchange (with surrounding area)	North	90/94	33.05%	9.52%	25.19%	57.44%	x
	Central	55/90/94	22.71%	15.85%	11.98%	61.44%	x
	South	x	x	x	x	x	x
Commercial – Urban	North	x	x	x	x	x	x
	Central	90/94, Wrigleyville	16.39%	38.54%	72.20%	45.07%	x
	South	Stony Island	15.51%	22.32%	53.75%	62.17%	x
Commercial – Suburban	North	Lincolnwood	11.59%	35.44%	59.00%	52.97%	x
	Central	Schaumburg	12.33%	23.18%	100.00%	64.49%	x
	South	x	x	x	x	x	x
Industrial	North	x	x	x	x	x	x
	Central	x	x	x	x	x	x
	South	Stockyards/International Amphitheater, Blue Island/Pilsen, Cicero	10.32%	42.05%	14.39%	47.63%	x

or high/medium density, category were: Rogers Park, 90/94 Interchange, Wrigleyville, Garfield Park, Lincoln Park, Blue Island/Pilsen, and Stony Island. The areas represented within the near suburban, or medium/low density, category were: Lincolnwood, Oak Lawn, and Cicero. Finally, only one area was represented within the far suburban, or low density, category: Naperville.

The variation within the recreational category was not primarily due to location; instead, it occurred because this category included analysis of large parks, small parks, and schools with athletic fields.

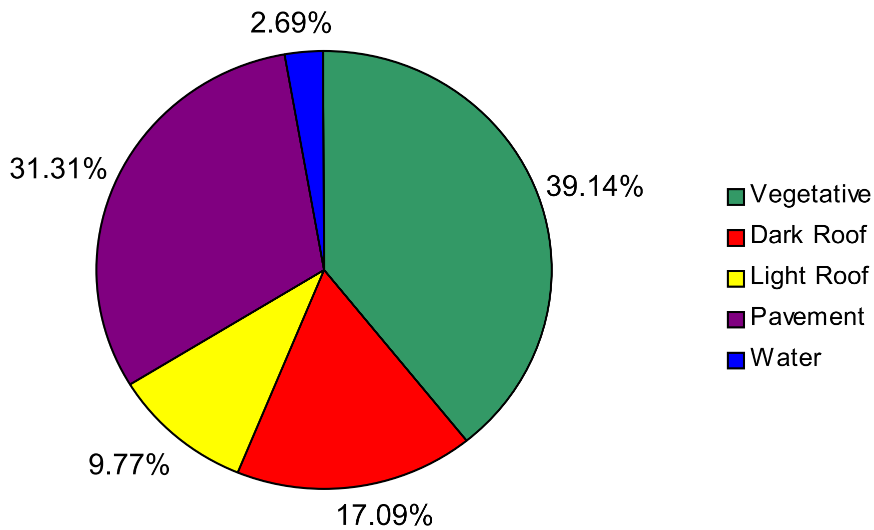
The transportation category included values based on major highways running through the downtown section of Chicago (i.e. 55, 90, & 94). This category only takes into account the highway system, median area, and shoulder region; it does not include any developed areas surrounding the highways.

The commercial category had the second greatest number of samples, 7, and represented both urban and suburban regions of Chicago. There again is variation within this category depending upon which areas were analyzed. The specific areas represented within the urban commercial category were: 90/94 Interchange, Wrigleyville, and Stony Island. The areas represented within the suburban commercial category included one near and far area: Lincolnwood and Naperville.

Finally, the variation within the industrial category occurred because this category includes the analysis of warehouses, stockyards, and industrial office complexes. Thus, the values within the industrial category varied depending upon what type of specific structures or buildings were present in the particular area analyzed.

Based on the average values for the each type of surface displayed in *Tables 9* and *10* and the overall land use breakdown given in *Figure 41*, the overall average urban fabric for all of the land use categories in Chicago was estimated and is summarized in *Figure 43*. This pie chart illustrates that the largest portion of Chicago's urban fabric is vegetative land cover at almost 40%, followed by paved at about 31%, and total roofed at approximately 27%. The following sections discuss with greater detail what was specifically observed within each of these land cover categories

Figure 43: Chicago's Urban Fabric



4.3.1. Chicago's Vegetative Cover

For vegetative surfaces, including both the ground and canopy cover, *Table 11* lists the order, from greatest to least, of each category and its corresponding percentage of the total urban fabric surface area.

Table 11: Vegetative Surface Cover for Chicago

CATEGORY	***PERCENTAGE VEGETATIVE***
Residential – Far Suburban (Low Density)	70.51 %
Recreational	67.19 %
Residential – Near Suburban (Medium/Low Density)	49.67 %
Residential – Urban (Medium/High Density)	45.12 %
Transportation	30.89 %
Commercial – Urban	16.10 %
Commercial – Suburban	12.15 %
Industrial	10.32 %

For more than 160 years, Urbs in Horto, "City in a Garden", has been Chicago's motto. There are currently 4.1 million trees in the City of Chicago (26), and a minimum of 5,000 new trees is planted each year by Chicago's Bureau of Forestry (49). The majority of Chicago's vegetative cover is located in residential and recreational areas. Street trees in particular are a significant part of this landscape, accounting for 10% of the city's trees and 24% of the total leaf surface area, which provides building and pavement shade and allows for the atmospheric exchange of gases.(26)

It is observed that for vegetative ground and canopy cover, there is a considerable percentage difference between the highest and lowest values. Specifically, the four highest percentages are at least 1.5 to 7 times greater than the five lowest ones. This indicates that vegetative planting strategies should be focused on the transportation, commercial, and industrial categories. Within these top four values it is also interesting to note that the urban and near suburban values are very similar to each other, which suggests that the densities of these areas are relatively equal.

In addition, the categories that have the highest percent of vegetative cover, residential and recreational, have the lowest percentage of paved surfaces, as seen in *Table 13*. This phenomenon is likely facilitated by not only greater amounts of vegetative ground cover, but by an increased contribution from the canopy cover of trees, that shade paved surfaces from solar radiation.

4.3.2 Chicago's Roofed Surface

For roofed surfaces, *Table 12* lists the order, from greatest to least, of each category and its corresponding percentage of the total urban fabric surface area.

Table 12: Roofed Surface Cover for Chicago

CATEGORY	***PERCENTAGE ROOFED***	***PERCENTAGE LIGHT/WHITE***
Industrial	42.05 %	14.39 %
Residential – Urban (Medium/High Density)	34.42 %	36.84 %
Commercial – Urban	33.14 %	66.05 %
Residential – Near Suburban (Medium/Low Density)	27.17 %	35.30 %
Commercial – Suburban	26.24 %	89.75 %
Residential – Far Suburban (Low Density)	12.70 %	27.45 %
Recreational	6.66 %	32.37 %
Transportation	0.00 %	0.00 %

The percentage of roofed surfaces indicates the quantity of buildings located within a particular land use category. It can be observed that the roofed surfaces in Chicago's far suburban residential and recreational areas are at least 2 to 7 times less than the other categories, which suggests that the building density in these areas is also lower.

For this fabric element, the percentage of the total roofed surface that is light/white in color could be extracted. This reveals that lighter roofing materials are already in frequent use in Chicago for all of the building categories analyzed. It is observed that by far the largest fraction of light roofs is related to the commercial category, at 66 - 90%; whereas the smallest fraction of light roofs is associated with the industrial category, at 14%. The residential and recreational categories, which constitute the lowest overall roofed surface percentages, fall between these other two land use types and show a relatively uniform light roofed coverage of approximately 30-35%. These results suggest that industrial and residential areas would receive the greatest benefit from an increased use of light colored roofed surfaces.

4.3.3 Chicago's Paved Surface

For paved surfaces, *Table 13* lists the order, from greatest to least, of each category and its corresponding percentage of the total urban fabric surface area.

Table 13: Paved Surface Cover for Chicago

CATEGORY	***PERCENTAGE PAVED***
Transportation	69.11 %
Commercial – Suburban	61.61 %
Commercial – Urban	50.77 %
Industrial	47.63 %
Residential – Near Suburban (Medium/Low Density)	23.16 %
Recreational	21.61 %
Residential – Urban (Medium/High Density)	20.47 %
Residential – Far Suburban (Low Density)	16.79 %

Currently, the primary components considered in the pavement selection of highway design are cost of construction, economy of maintenance, durability, and safety.(40) In general, asphalt roads are less expensive to build and maintain than concrete roads when costs are compared over short time intervals (less than 20 years) and do not incorporate environmental impacts. However, concrete pavement becomes more cost effective (using conventional cost comparison techniques) when the roadway can be built in long sections, such as that produced using the slip form pavement technique.(50) Unfortunately, city roadways have many obstacles, associated with utility placement and accessibility, which requires the road to be built in a series of relatively short individual sections. Therefore, the construction and repair costs analogous with concrete city roadway are higher relative to asphalt city roads.(51)

Within the city of Chicago, roads are constructed using a nine inch concrete based with a three inch asphalt overlay.(51) This technique, however, does not apply to all of the roadways in Chicago. This is due to the presence of state and county roads, which are built to different specifications.

It should also be noted that for paved surface cover there is a considerable percentage difference between the highest and lowest values; specifically, the four highest percentages are at least 2 to 3 times greater than the four lowest ones. This suggests that cool pavement strategies should be focused on the transportation, commercial, and industrial categories. Specifically, a focus should be placed upon the western suburban commercial areas, which maintain the highest percent paved surface cover, have the largest amount of new development, and which are located in and around the core of the Chicago heat island.

In addition, in relation to alleys, it was observed that they are significantly present only within the urban and near suburban areas of the residential category. They comprise approximately 15% of the total paved surface, which are in turn approximately 3.5% of the total overall urban fabric surface area. Thus, it may not be very practical to focus a substantial amount of money and attention to the repavement of the city's alleys.

5. CONCLUSIONS

5.1 URBAN HEAT ISLAND AND OZONE

High rates of urbanization have resulted in drastic demographic, economic, land use, and climate changes in urban areas. These changes in turn have created urban microclimates, referred to as urban heat islands, which exhibit elevated air temperatures of 2-8°F, increased energy demands, elevated pollution concentrations, and increased human health and environmental risk compared to surrounding areas. Most cities today exhibit heat island effects relative to predevelopment conditions; however, their individual intensities depend on a number of factors: geography, topography, land use, population density, and physical layout.

Urban areas are not only centers of heat, but also of air pollution in the form of photochemical smog. The primary active pollutants in the creation of photochemical smog are nitrogen oxides (NO_x) and volatile organic compounds (VOCs). In the presence of sunlight, these reactants are rapidly converted to secondary pollutants, most of which is ozone. Thus, ozone exists in the troposphere as the primary ingredient in photochemical smog and has detrimental effects on human health and the environment.

The elevated temperatures of cities accelerate the photochemical formation of ozone and are considered a primary causative factor in smog episodes. There are numerous reasons hypothesized to explain the positive correlation observed between ozone and temperature. The first of these is related to the increase in photolysis rates of ozone production with increasing temperature and under meteorological conditions associated with high temperatures. A second reason is attributed to an increase in the production of ozone precursors, such as NO_x and VOC, at high temperatures. This hypothesis arises from the fact that higher temperatures create increased energy use, mostly due to a greater demand for air conditioning in buildings and automobiles. Thus, as power plants burn more fossil fuels to meet this increase in energy demand, they generate a greater quantity of emissions, which increases the levels of ozone precursors present at ground level. Finally, the relationship between high temperatures and stagnant circulation patterns, as discussed previously, can be used to account for the notable trend between ozone and temperature. Unfortunately, an exact mechanistic understanding of the relationships between all these factors thought to contribute to elevated ozone concentration does not currently exist. Thus, each city tends to exhibit a unique relationship between temperature and maximum ozone concentration.

In general, the modification of an urban surface to include more vegetative cover and lighter, lower albedo surfaces is believed to decrease temperatures, energy consumption, ozone exceedances, and detrimental environmental and human health effects associated with high levels of ozone. This thesis evaluates the accuracy of this premise for the metropolitan Chicago area.

5.2 THE CHICAGO REGION

Chicago is among the cities classified as severe ozone nonattainment areas, making it a likely candidate for a case study evaluating the estimated effects of cooling strategies to abate the urban heat island effect and ozone problem in Chicago. The purpose of this project was to identify the relationship between temperature and ozone in the Chicago region, locate the heat island in Chicago, and describe the regional features associated with ozone exceedances. In addition, an urban fabric analysis of Chicago was conducted as the first step towards investigating the effect that surface modifications have on the urban heat island phenomenon and related ozone problem in the metropolitan area of Chicago, IL. Finally, to aid in the analysis of surface modifications, a full life cycle analysis, including environmental costs and factors, of concrete verses asphalt pavement was reviewed.

5.2.1 Temperature and Ozone Relationship in Chicago

The Chicago area ozone and temperature relationship was found to be complicated and in contrast to data from other northern cities, upon analysis of the ozone verses temperature data for Chicago, a rather weak correlation is observed. There is, however, a temperature threshold of approximately 80°F below which very few ozone exceedances are observed. Furthermore, for all the monitoring stations studied, the number of ozone exceedances at a particular temperature above 80°F relative to the total number of days registering that temperature is typically 1% or less, except at the extreme temperatures above 95°F.

This phenomenon suggests that there are other factors present that dictate the quality of Chicago's air. In fact, our analysis, in conjunction with studies conducted by the Ozone Transport Assessment Group (OTAG), established that Chicago's ozone problem is strongly correlated with wind patterns and atmospheric transport. It is also likely that Chicago's emissions act as precursors for the formation of ozone over Lake Michigan, western Michigan, and eastern Wisconsin. As a result, the control and reduction of ozone and its precursors require addressing regional mobile, point, and area sources.

Although elevated summertime temperatures do not appear to be a direct causative factor in ozone exceedances in the metropolitan Chicago area, there may be an indirect relationship between high temperatures, increased energy demand, and ozone. The high cooling demand may contribute to greater emissions of ozone precursors due to elevated energy use. Thus, a more compelling reason to lower summertime temperatures in Chicago may be related to diminished energy use, decreased fossil fuel consumption, and reduced emissions.

5.2.2 Chicago's Urban Heat Island and Ozone Distribution

The temperature profile of a heat island can vary significantly throughout an area. Thus, in order to assess the location of the Chicago heat island, the temperature distribution, for the summer months (June-August) for the 1992-1996 time frame, was analyzed. Results show that the actual heat island in the Chicago area consistently appears in the western suburbs (specifically over Lisle), not in the Downtown area. An examination of the ozone data for the Chicago Area, specifically Cook County, revealed that the majority of the noncompliance days are also not in Downtown Chicago. Instead, they appear centered around the northern suburbs.

When the heat island and ozone distribution in Chicago are compared, it is observed that the ozone noncompliance distribution does not correspond with the heat island and the maximum is over an area with few known emissions sources. These results are consistent with the finding that maximum ozone levels are not positively correlated with temperature and support the hypothesis that atmospheric and surface transport mechanisms greatly influence the ozone distribution in the Chicago area. This conclusion, in association with other research conducted within this area (28,17), furthers the hypothesis that ozone is a regional issue and during the summer ozone season, prevailing southeasterly transport wind vectors frequently ventilates the Chicago Area. These winds assist in the redistribution of high precursor and ozone concentrations beyond their originating sources to adjacent areas with little to no emissions sources.

In general, all the noncompliance days in the Chicago Region occur in the deep summer months (June-August) and at relatively high temperatures, almost 70% above 85°F. Of the eight noncompliance days from 1992-1996 that occurred at a temperature below 85°F, only three exceedance measurements were made in the city limits of Chicago. The other five ozone exceedances occurring at temperatures below 85°F were measured in the Northern Suburbs of Chicago. At all of the aforementioned locations, it is likely that factors other than temperature are at play, although it can be assumed that a portion of the ozone originates from within the domain as a result of the reactions of O_3 precursors.

5.2.3 Cooling Chicago

Urbanization of the natural landscape through the replacement of vegetation with roads, bridges, houses, and commercial buildings has dramatically altered the temperature profile of cities. While many of the factors that influence the formation of urban heat islands, including climate, topography, and weather patterns, can not be changed or altered, efficient and cost-effective ways of mitigating heat islands do exist. Two heat island factors attributable to human activities can be readily controlled: the amount of vegetation and the color of surfaces.(3) Increasing vegetative cover through strategic landscaping around buildings and throughout cities can absorb solar radiation, provide shade, and control wind flow benefits. Changing dark colored surfaces to light colored ones would more effectively reflect, rather than absorb, solar energy and emit stored heat energy at a higher rate, thus reducing the cooling energy loads and ground level air temperatures influenced by these surfaces.

The use of cooling strategies if applied to the metropolitan Chicago area can be expected to produce a proportional decrease in temperature. However, since few ozone noncompliance days are solely the result of temperature effects and the majority occur at temperatures above 85°F, a four degree decrease in temperature, as found in simulations of surface modification within the LA Basin (3,4), would probably have a minor effect on the overall number of ozone noncompliance days in the Chicago area. Assuming simulations in Chicago produce results similar to the LA Basin and based upon observed data, a 10-12% reduction in the total number of ozone noncompliance days would translate into only approximately 0.6 days per year. Therefore, it is important to consider and examine more fully the other benefits, in addition to lower ozone levels, that are promoted via cooling strategies. These additional benefits include reduced energy demands, enhanced human health and ecological protection, and increased comfort.

While little resistance is encountered in devising programs to increase tree plantings and vegetative cover, greater obstacles are met with efforts to change construction and paving practices. This report has focused on evaluating the impacts and costs associated with asphalt verses concrete pavement.

Traditionally in life cycle cost analysis, an emphasis has been placed on the respective costs of different pavement alternatives throughout their design lifetimes. As a result, when concrete and asphalt systems are compared, the asphalt pavement alternative was usually selected because a concrete system is more expensive to construct and maintain.(35) However, increased concern over improving the sustainability of engineered operations has promoted the need to look at the fuller perspective. Thus, new life cycle assessment strategies are being developed that account for factors such as resource depletion, human health effects, and environmental impact in product selection.

Life cycle assessment, using environmental value engineering, employs a systems approach methodology to more accurately compare the input requirements and related environmental impacts of pavement alternatives.(42) As a result, when concrete and asphalt highway pavement systems are compared using this revised life cycle analysis approach, concrete proves to be superior. In fact, it was shown in the example presented in section 3.2.4. that based on a normalized unit of comparison, concrete is approximately 47.6% more efficient overall than asphalt.

Unfortunately, the current market and technology barriers to shifting from the use of asphalt as a repair and resurfacing material to concrete or another alternative material are substantial in many areas for reasons often associated with experience, material handling, ease of construction, and amortized cost over short time intervals. Moreover, it should be noted that these results only represent one particular approach. Thus, in order to develop a more compelling and convincing perspective, additional life cycle assessment techniques must be considered.

5.2.4 Chicago's Urban Fabric

Land use and surface cover are elements of the urban fabric that are commonly altered during the development of metropolitan areas. Because these elements, which include vegetation, building roofs, and pavements, act as the active thermal interfaces between the atmosphere and land surfaces, their composition and structure within the urban canopy layer largely determine the thermal behavior of different areas within a city. Thus, the alteration of these surfaces results in the creation of numerous urban microclimates, the combined result of which is referred to as the heat island effect.(52)

In order to accurately analyze the effect of surface cover modifications, attain pertinent results, and eventually simulate realistic estimates of temperature and ozone reductions resulting from these modifications, the current urban fabric of the Chicago area was evaluated as it relates to land use. This analysis was accomplished using color aerial photographs to determine the proportions of vegetative, roofed, and paved surface cover within each of the five land use categories: residential, recreational, commercial, industrial, and transportation.

From this urban fabric analysis it was found that the residential vegetative cover was relatively high, above 45%, over all the different density areas within the city of Chicago. Thus, it was also concluded that Chicago is already doing a relatively good job in the residential areas with respect to maintaining a high vegetative cover to paved surface ratio, of approximately 2.2-4.2. In contrast, the commercial and industrial areas in the Chicago area had the lowest proportion of vegetative cover, about 10-16%. As a result, programs that promote tree planting and increased vegetative cover should be concentrated primarily on the commercial and industrial areas in the Chicago region.

The analysis of roofed surface cover revealed that this percentage is dependent upon the building density within a particular land use category. Thus, it was observed that recreational and far suburban residential areas contained the least relative amount of roofed surfaces, less than 13%, for they have the lowest building density associated with them. In addition, when light/white roofs were separated out, it was revealed that lighter roofing materials are already in wide use in Chicago with the greatest percentage of light/white roofs was found in commercial areas, 66-90%. This point illustrates the ease of employing light roofing materials, in the construction and resurfacing of building roofs, as a feasible heat island mitigation strategy in the

Chicago area. Specifically, an emphasis should be placed on the suburbs where a high degree of development is occurring.

The paved surface cover was found to be the greatest in the transportation, commercial, and industrial areas, where its proportion is above 50%. In addition, the vegetative cover to paved surface ratio in these three areas is small, about 0.2-0.5. Thus, a concentration should be placed upon developing and implementing mitigation strategies within the transportation, commercial, and industrial areas of Chicago. These mitigation strategies should include a focus on greater use of concrete over asphalt, and in general, an emphasis should be placed on the use of higher albedo paving materials in the suburban areas that almost exclusively use asphalt for pavement. However, a change to the utilization of concrete over asphalt will require urban and suburban planners to compare costs over longer design lives and consider all the environmental costs associated with a material's use, neither of which is currently done. The life cycle analysis reviewed herein presents one methodology for making such a comparison.

APPENDIXES

A. Illinois Statewide Ozone Precursor Emissions Inventory – 1996 Typical Summer Day Emissions of Oxides of Nitrogen (NO_x) Chicago Nonattainment Area

B. Illinois Statewide Ozone Precursor Emissions Inventory – 1996 Typical Summer Day Emissions of Volatile Organic Materials (VOC) Chicago Nonattainment Area

C. Transformities/Emergy Conversions

D. Urban Fabric Analysis Sector Locations

E. Urban Fabric Analysis Results

APPENDIX A