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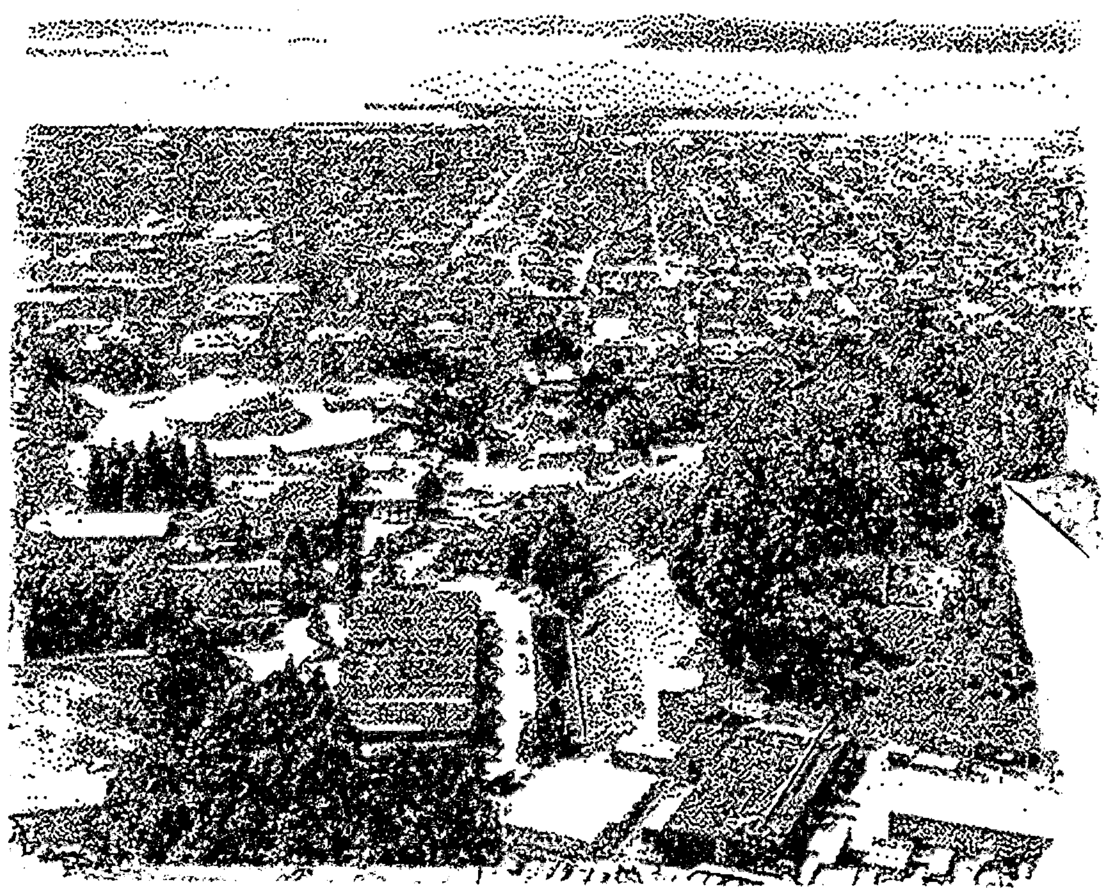

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Characterizing the Fabric of the Urban Environment: A Case Study of Metropolitan Chicago, Illinois

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Abstract

Urban fabric data are needed in order to estimate the impact of light-colored surfaces (roofs and pavements) and urban vegetation (trees, grass, shrubs) on the meteorology and air quality of a city, and to design effective implementation programs. In this report, we discuss the result of a semi-automatic Monte-Carlo statistical approach used to develop data on surface-type distribution and city-fabric makeup (percentage of various surface-types) using aerial color orthophotography. The digital aerial photographs for metropolitan Chicago covered a total of about 36 km^2 (14 mi^2). At 0.3m resolution, there were approximately 3.9×10^8 pixels of data.

Four major land-use types were examined: commercial, industrial, residential, and transportation/communication. On average, for the areas studied, at ground level vegetation covers about 29% of the area (ranging 4–80%); roofs cover about 25% (ranging 8–41%), and paved surfaces about 33% (ranging 12–59%). For the most part, trees shade streets, parking lots, grass, and sidewalks. In commercial areas, paved surfaces cover 50–60% of the area. In residential areas, on average, paved surfaces cover about 27% of the area.

Land-use/land-cover (LULC) data from the United States Geological Survey was used to extrapolate these results from neighborhood scales to metropolitan Chicago. In an area of roughly 2500 km^2, defining most of metropolitan Chicago, over 53% is residential. The total roof area is about 680 km^2, and the total paved surfaces (roads, parking areas, sidewalks) are about 880 km^2. The total vegetated area is about 680 km^2.

Executive Summary

The Heat Island Reduction Initiative (HIRI) is a joint program sponsored by the U.S. Environmental Protection Agency (EPA) and the Department of Energy (DOE) to encourage the use of strategies designed to reduce demand for cooling-energy use and prevent smog formation. As part of the initiative, the Urban Heat Island Pilot Project (UHIPP) was launched to quantify the potential impacts of heat island reduction strategies in terms of energy savings, economic benefits, and air-quality improvements. EPA selected five metropolitan areas of Sacramento, CA, Salt Lake City, UT, Chicago, IL, Houston, TX, and Baton Rouge, LA for the UHIPP study. Since the inception of the project, LBNL has conducted detailed studies to investigate the impact of mitigation technologies on heating and cooling energy use in these pilot cities. In addition, LBNL has collected urban surface characteristic data and conducted meteorology and urban smog simulations for the four pilot cities.

One of the components of UHIPP research activities is to analyze the fabric of the pilot cities by accurately characterizing various surface components. This is important since the fabric of the city is directly relevant to the design and implementation of heat-island reduction strategies. Of particular importance is the characterization of the area fraction of various surface types as well as vegetative cover. Accurate characterization of the urban fabric would allow the design of implementation programs with a better assessment of the cost and benefits of program components. In addition, the results of such detailed analysis will be used in simulating the impact of heat-island reduction strategies on local meteorology and air quality.

In this report, a method is discussed for developing high-quality data on surface-type distribution and city-fabric makeup (percentage of various surface-types) using aerial color photography. This method was initially applied to obtain data for Sacramento CA. Here we apply the method to obtain data for the fabric of metropolitan Chicago, IL.

The imagery for metropolitan Chicago covered a total of about 36 km^2 (14 mi^2). **Picture EX.1** depicts a sample photograph in metropolitan Chicago. At 0.3-m resolution, there were approximately 3.9×10^8 pixels of data. We devised a semi-automatic method to sample the data and visually identify the surface-type for each pixel. The method involves four steps:

1. visually inspecting aerial photographs and preparing of a list of various surface-types identifiable in the photos;
2. grouping surface categories into major types;
3. randomly sampling a subset of data for each region (through a Monte-Carlo sampling approach), and visual inspection of each sample and the assignment of a surface classification to it (these surface classifications are summarized in Table EX.1); and
4. extrapolating the results to the entire metropolitan Chicago using the United States Geological Survey (USGS) land-use/land-cover (LULC) data as a basis.

The classification in Table EX.1 may include more detail than necessary (even more details can be seen in the photos though, for example, mailboxes, small benches, etc., that are, of course, irrelevant to this task). A distinction was made between Category 1, "Unidentified," and Category

30, "Other Feature." Those surfaces classified as "Unidentified" could not be accurately defined, while those in the "Other Feature" category could be, but were not relevant to this study. This distinction was necessary to avoid assigning these known features incorrectly.

Table EX.1. Visually identifiable features of interest in the metropolitan Chicago (based on aerial photographs).

Category	Description	Category	Description
1	Unidentified	16	Swimming Pool
2	Tree Covering Roof	17	Auto Covering Road
3	Tree Covering Road	18	Private Paved Surfaces
4	Tree Covering Sidewalk	19	Parking Deck
5	Tree Covering Parking	20	Alley
6	Tree Covering Grass	21	Water
7	Tree Covering Dry/Barren Land	22	Grass on Roof
8	Tree Covering Other	23	Train Tracks
9	Tree Covering Alley	24	Auto Covering Parking
10	Roof	25	Recreational Surface
11	Road	26	Residential Driveway
12	Sidewalk	27	Awning
13	Parking Area	28	N/A
14	Grass	29	N/A
15	Dry/Barren Land	30	Other Feature (not of interest)

The various tree categories (Categories 2–9) were later grouped under one category (designated as "Trees"). For meteorological modeling purposes, one tree category is sufficient to determine the fraction of vegetation in the urban area. However, for implementation purposes, one would like to "see" what lies beneath the canopy of trees. Thus in this case the areas beneath the trees are simply totaled and the tree canopy ignored, assuming trunk area is negligible. As shown in **Table EX.2**, categories of related surface-types were grouped in representative types for an "above-the-canopy" perspective. The grouping was done in order to aggregate similar surfaces that may also have similar albedos.[1] For instance, the "Sidewalk" surface-type is the total of the "Residential Driveway" and "Sidewalk" categories since in the areas analyzed, these categories both appeared to be light-colored concrete. "Parking Area" is the total of parking lots and decks, "Grass" is the total of ground-level grass and roof grass, and the category "Miscellaneous" is the total of sporadic surface-types such as swimming pools, water, alleys, autos, private surfaces, and train tracks. For characterization of the surfaces "under-the-canopy," the primary criterion for grouping was the function or use of the surface-type. For instance, the under-the-canopy "Roof" category include: "Tree Covering Roof" (Cat. 2), "Roof" (Cat. 10), "Parking Deck" (Cat. 19), "Grass on Roof" (Cat. 22), and "Awning" (Cat. 27). Table EX.2 also shows the assignment of various categories (identi-

[1] When sunlight hits an opaque surface, some of the energy is reflected (this fraction is called albedo = â) and the rest is absorbed (the absorbed fraction is 1-â). Low-a surfaces of course become much hotter than high-a surfaces.

fied in Table EX.1) to surface-types under the canopy. Under-the-canopy characterization also includes a new general category, "Private Paved Surfaces," to distinguish between public surfaces and those surfaces owned privately. The "Tree Cover" category was eliminated, since at the ground level there is no tree canopy.

Table EX.2. Major surface-types

Surface-Type	Categories Included*	Surface-Type	Categories Included
Above-the-Canopy View			
Roof	10, 27	Tree Cover	2–9
Road	11	Grass	14
Parking Area	13, 19	Barren Land	15
Sidewalk & Driveway	12, 26	Miscellaneous	16–18, 20, 21, 23–25, 30
Under-the-Canopy View			
Roof	2, 10, 19, 22, 27	Private Paved Surfaces	18, 26
Road	3, 9, 11, 17, 20	Grass	6, 14
Parking Area	5, 13, 24	Barren Land	7, 15
Sidewalk	4, 12	Miscellaneous	8, 16, 21, 23, 25, 30

* Surface-type categories are defined in Table EX.1.

Results from this analysis suggest several possible land-use and surface-type classification schemes for the metropolitan Chicago area. In this study, the major land-use types examined were commercial, industrial, residential, and transportation/communication. Fifteen different areas were selected for this analysis. For each of these areas, up to 28 different surface-types were identified and their fractional areas computed. The results are shown in **Figures EX.1** (above-the-canopy view of the city) and **EX.2** (under the tree canopy). In the commercial section of suburban Chicago, the top view (above the canopy) shows that vegetation (trees, grass, and shrubs) covers 18% of the area, whereas roofs cover 15–25% and paved surfaces (roads, parking areas, and sidewalks) cover 50–54%. The under-the-canopy fabric consists of 53–59% paved surfaces, 15–25% roofs, and 14–18% grass. In the industrial areas, above the canopy, vegetation covers 4–17% of the area, whereas roofs cover 29–41%, and paved surfaces 29–31%. Residential areas exhibit a wide range of percentages among their various surface-types (See **Figure EX.3** and **EX.4**). On the average for residential areas, above the canopy, vegetation covers about 45% of the area (ranging from 24% to 80%), roofs cover about 27% (ranging from 8% to 37%), and paved surfaces about 26% (ranging from 12% to 35%).

In order to extrapolate these results from neighborhood to regional scales, e.g., regional metropolitan Chicago, land-use/land-cover (LULC) data from the United States Geological Survey (USGS) was used as a basis for mapping the area distributions. In this method, the metropolitan

Chicago LULCs were mapped onto those of the USGS and the total areas of surface-types were calculated for the entire region of interest. Of the total domain area of approximately 18,500 km^2, about 2,500 km^2 is categorized as urban area of which approximately 53% is residential (see **Figure EX.5a**). The total roof area as seen above the canopy comprises about 26% of the urban area (about 600 km^2); total paved surfaces (roads, parking areas, sidewalks) are 33% (about 750 km^2); and total vegetated area covers about 33% (750 km^2) (see **Figure EX.5b**). The actual total roof area as seen under the canopy comprises about 27% of the urban area (about 680 km^2), total paved surfaces (roads, parking areas, sidewalks, and private surfaces) are 35% (about 880 km^2), and total vegetated area (only grass and bushes) cover about 27% (680 km^2) (see **Figure EX.5c**).

Metropolitan Chicago is fairly green, but the potential for additional urban vegetation may be large. In the commercial and industrial areas, existing trees shade about 0–5% of the grass area and 0–10% of all paved surface areas. In some residential areas, trees shade up to 12% of grass and up to 15% of the paved surfaces. The fraction of roof areas shaded by trees is less than 1%. If we assume that trees can potentially shade 20% of the roof area, 20% of roads, 50% of sidewalks, 30% of parking areas, they would add up to about 14% in additional tree cover for the entire city (the validity of these assumptions need to be checked in a detailed study). An additional tree cover of 14% amounts to about 350 km^2 of the urban area. Assuming that an average tree can have a horizontal cross-section of about 50 m^2, these calculations suggest potential for 7 million additional trees in metropolitan Chicago. As climate and air-quality simulations have indicated, 7 million additional trees may have a significant impact on cooling metropolitan Chicago and improving ozone air quality.

The potential for increasing the albedo of metropolitan Chicago is also large. Impermeable surfaces (roofs and pavements) amount to 61% of the total area of metropolitan Chicago. Unfortunately, the aerial orthophotos for Chicago cannot be used to accurately estimate the albedo of the surfaces. For illustration purposes, if we assume that the albedo of the residential roofs can increase by 0.2, commercial roofs by 0.3, roads and parking areas by 0.15, and sidewalks by 0.1, the albedo of the urban areas in Chicago can then be increased by about 0.16. Like urban vegetation, increasing albedo would reduce the ambient temperature and in turn reduce ozone concentration in the city.

These results are based on a limited analysis for one city. In metropolitan Chicago there is a significant variation in the fabric of the neighborhoods selected for this analysis. Although an attempt has been made to select neighborhoods that represent the variation in the overall communities, these results should not be extrapolated to other cities and regions. Many cities are unique in terms of land-use patterns and constructions (e.g. most urban homes in the west coast are single story as opposed to two-story houses in the east). It is recommended that a similar analysis for several other cities in different regions of the country be performed in order to expand our understanding of the fabric of the city.

Picture EX.1. Aerial photo of a commercial area in metropolitan Chicago.

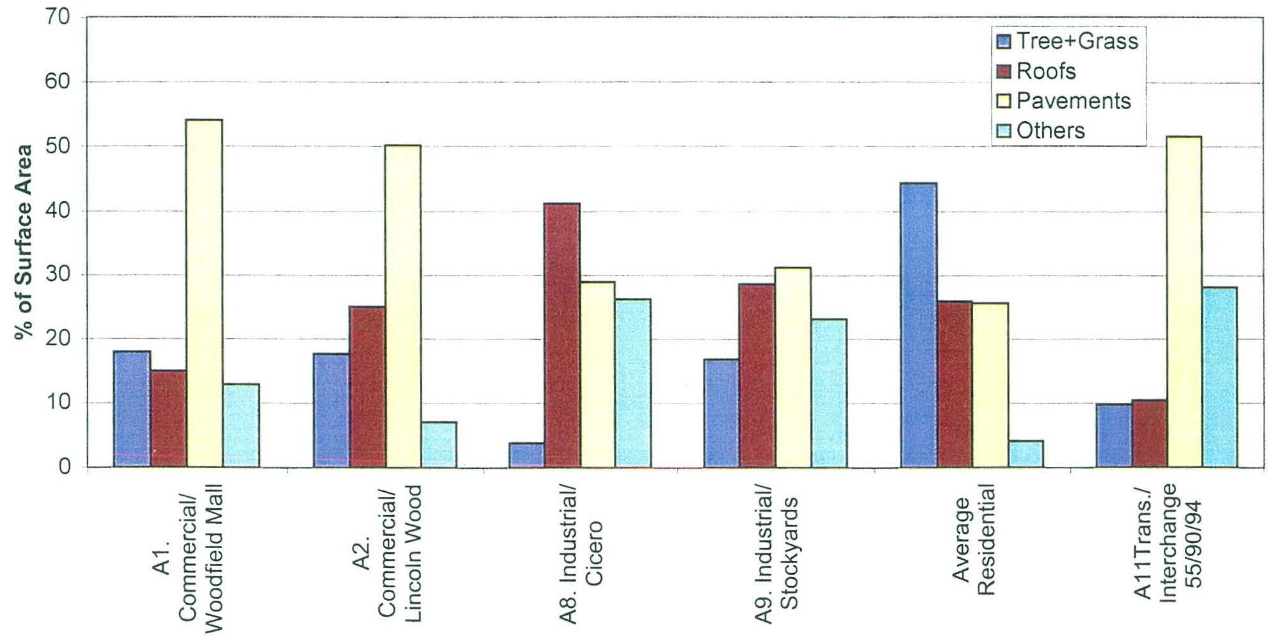


Figure EX.1. Above the canopy fabric of metropolitan Chicago, IL.

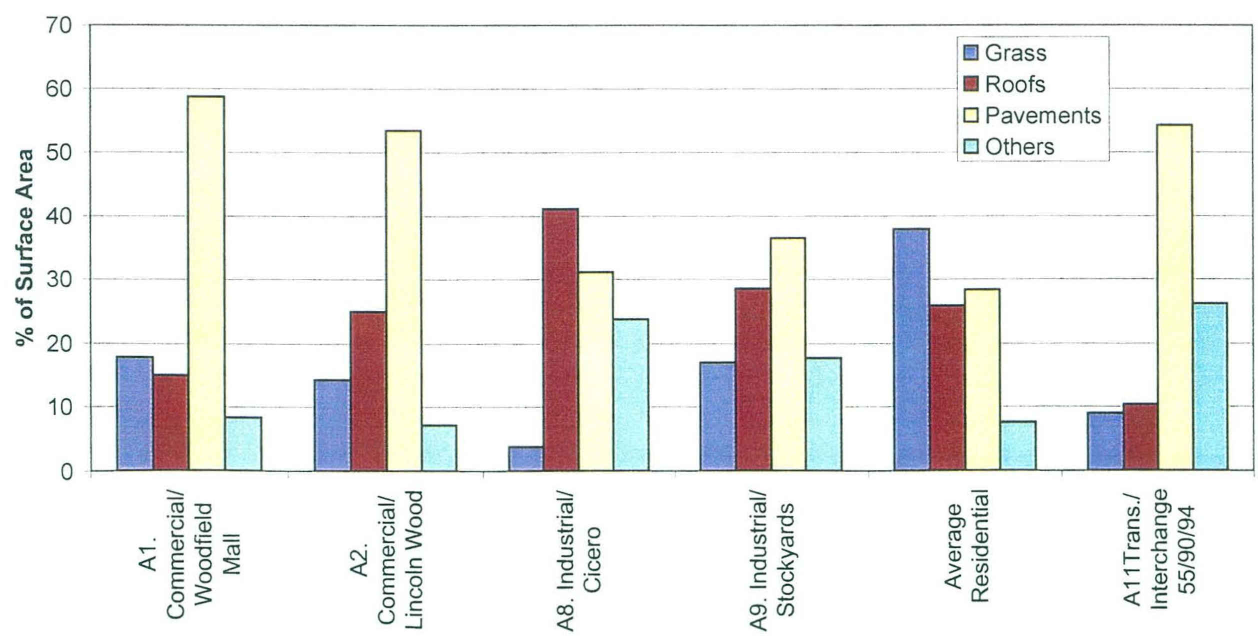


Figure EX.2. Under-the-canopy fabric of metropolitan Chicago, IL.

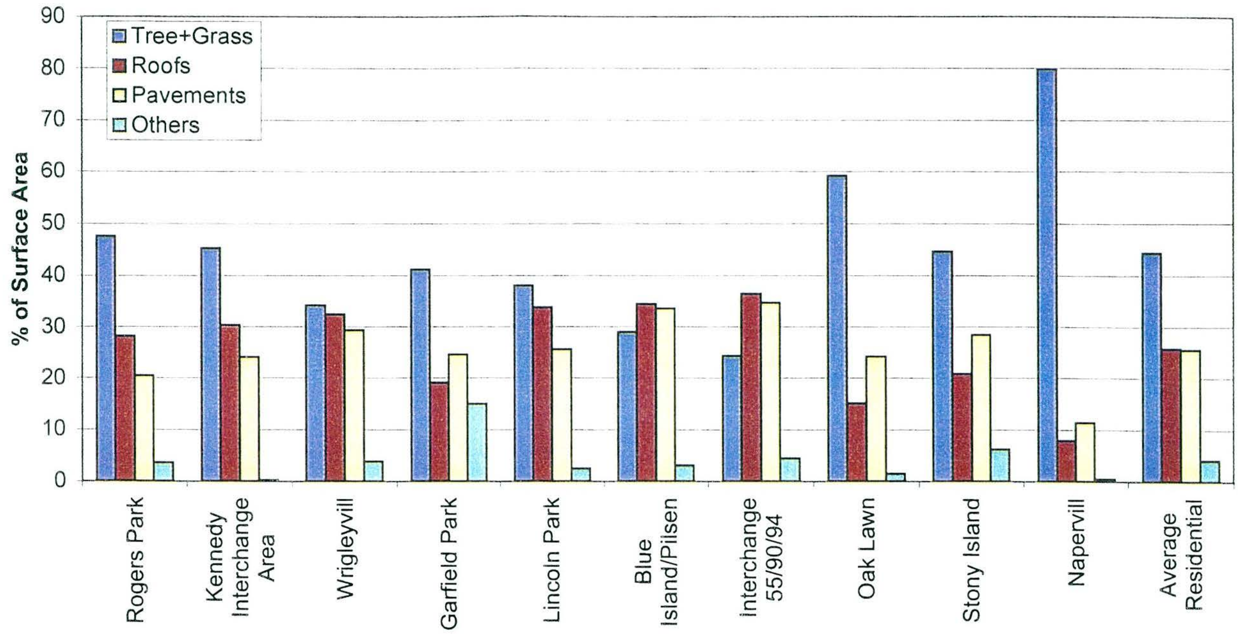


Figure EX.3. Above-the-canopy fabric of residential metropolitan Chicago, IL.

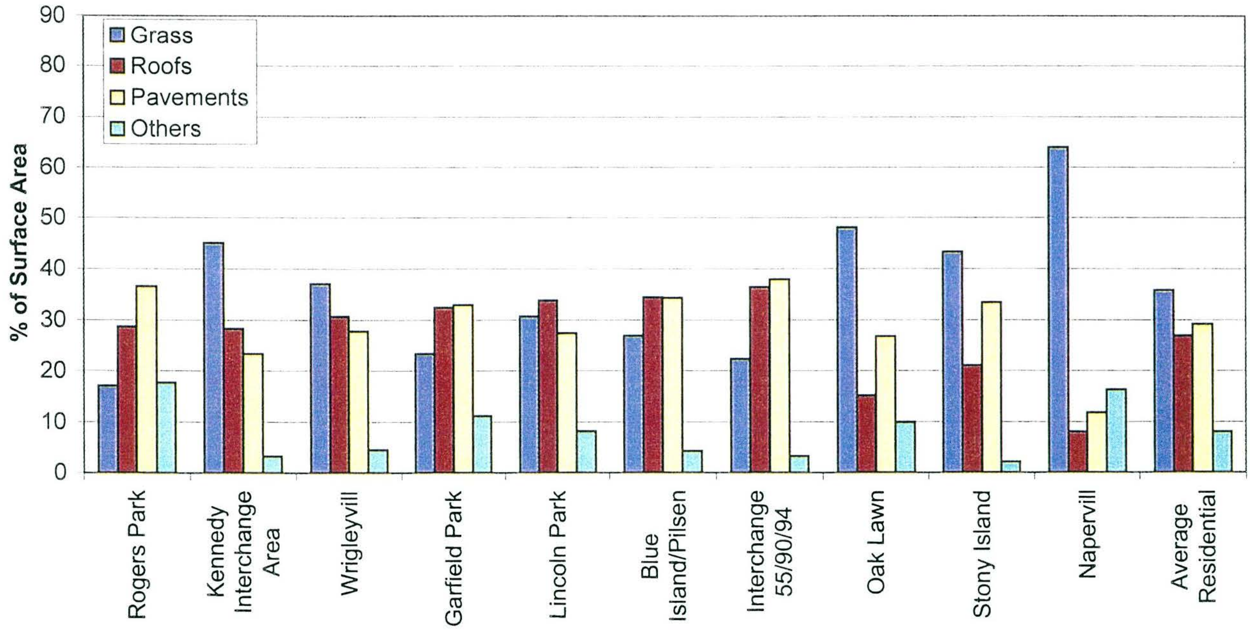
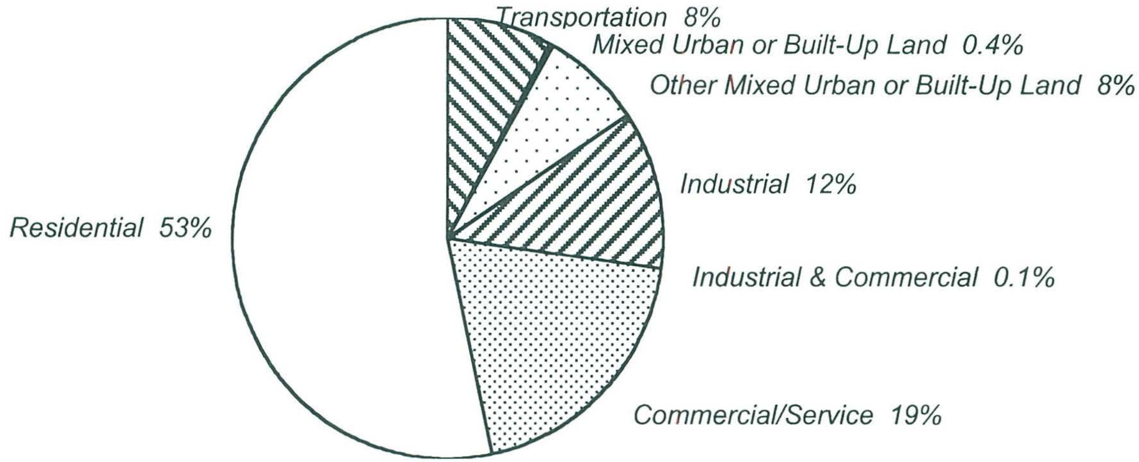
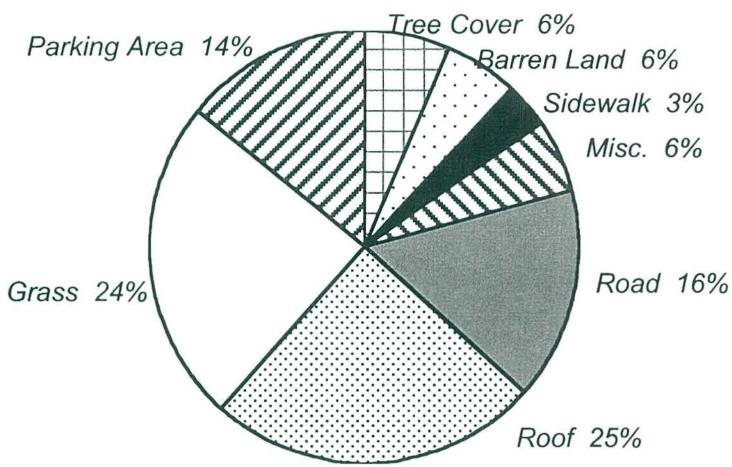


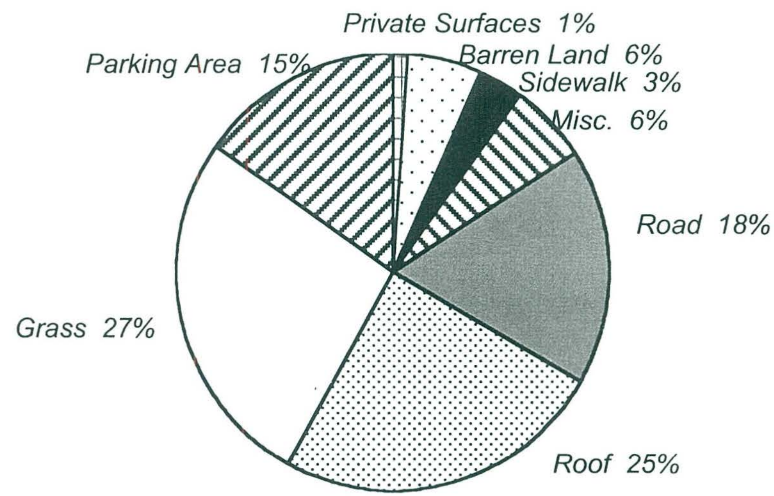
Figure EX.4. Under-the-canopy fabric of residential metropolitan Chicago, IL.



a) Area by USGS LULC Categories



b) Area by Land-Cover Category Above the Canopy



c) Area by Land-Cover Category Under the Canopy

Figure EX.5. Land use/land cover of the entire developed area of metropolitan Chicago, IL

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