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Planting Guidelines for Home Energy Savings

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주택 에너지 절약을 위한 식재계획 지침

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요 약

본 연구의 목적은 주택의 냉방 및 난방에너지 절약을 위한 적절한 식재계획의 지침을 제시하기 위함이었다. 본 연구의 대상지는 미국 중동부 내륙의 한 도시인 쉬카고(Chicago)의 북서쪽에 위치한 주거지였다. 쉬카고는 온대 기후대에 속하는 도시로서, 본 연구는 한국 중부지역의 주택들에 있어서 식재를 통해 냉방 및 난방에너지를 절약하고, 또한 그 에너지 절약으로부터 대기오염물의 배출을 저감하는데 유용한 정보를 제공할 것이라고 사료된다. 본 연구는 주택의 에너지 절약에 기여하는 주택주변 현존 식생의 차양(Shading), 증발산 및 방풍의 효과를 모델링하였다. 식재로부터 절약된 에너지의 총비용은 식생피도가 58.9%인 주거블럭에서 1993년 한해동안 한 가구당 46.3 달러였다. 그 중, 증발산효과가 53.7%, 방풍효과가 26.1%, 차양효과가 20.2%를 각각 차지하였다. 한편, 피도가 36.3%인 주거블럭에서의 연간 총 에너지 절약은 가구당 8.6 달러였다. 식생피도가 높은 주거지에서 식재에 의한 에너지 절약의 효과는 더욱 증대되었다. 그러나, 대부분의 현존 수목은 부적지에 위치되어 겨울철에 주택내로의 광선의 입사를 차단함으로써 난방에너지의 요구를 증가시켰다(수목 한 개체당 최대 6 달러). 차양효과를 최대화하기 위해서는 주택건물의 남쪽가까이에서는 교목의 식재를 가급적 회피하고, 수관이 가능한 한 넓은 교목을 주택건물의 서쪽과 동쪽가까이에 식재하여야만 한다. 증발산과 방풍의 효과를 증진하기 위해 건물의 북쪽, 북동쪽 및 북서쪽에서의 고밀도 식재가 요구된다.

Ⅰ. Introduction

Urban greenspaces help save cooling energy by a) blocking solar radiation reaching building structures through shading, and b) creating cool micro-climates near homes and buildings through evapotranspiration. They also reduce heating demand by decreasing air infiltration into and heat conduction out of the interior of buildings(miller, 1988).

Parker(1983; 1989) estimated that properly placed trees and shrubs can reduce summer cooling energy of a residential building by more than 50 percent in southern Florida. Huang et al.(1992) reported that a 10 percent increase in tree cover(corresponding to one tree per house) can save annual cooling energy by 24 percent in Sacramento and 12 percent in

Phoenix and Lake Charles, corresponding to annual dollar savings of $40 to $90 per house. It is reported that most of the cooling energy savings can be attributed to the effect of evapotranspiration and only 10 to 30 percent to shading(Huang et al., 1987). DeWalle(1978) found that proper arrangement of vegetation around a building can reduce winter heating costs by 4 to 22 percent. DeWalle et al.(1983) and Heisler(1991) estimated that windbreak planting around unprotected homes can reduce heating costs by 10 to 30 percent.

Based on the above, it is evident that proper planting design in residential areas including species selection and location can significantly save cooling and heating energy. A 3 percent reduction in home heating and cooling costs would save over 153 trillion Btus costing over $1 billion per year in the U.S. (U.S. Dept. of Energy, 1985). A reduction in home energy demand also helps mitigate emissions of air pollutants(including CO_2, a major greenhouse gas) from consumption of fossil fuels.

The purpose of this study was to suggest proper planting guidelines to save home cooling and heating energy. First, this study quantified shading, evapotranspiration, and wind reduction effects of existing vegetation on energy use of residential neighborhoods in Chicago, U.S.A. Second, the study modeled shading effects in various locations of trees to find out the optimum location. Most of present studies on cooling energy savings have been conducted in hot climate regions of the U.S. (Huang et al., 1987; McPherson et al., 1989; Parker, 1989; McPherson and Sacamano, 1992). A result of studies in the hot climate regions might not always be applied to all climate regions due to different weather conditions. A result of this research for an American city in temperate regions could be more appropriate for the application to the middle regions of Korea.

II. Methods

1. Study area

Two residential blocks located in northwest Chicago were selected as the study area. The criteria for selection of the study blocks were accessibility for data collection, similarity in building construction date, and difference in vegetation cover. Areal vegetative cover is significantly higher in study block 1 than in study block 2. Block 1 is enclosed by W. Catalpa Ave. and W. Rascher Ave., and N. Virginia Ave. and N. Francisco Ave. Block 2 is enclosed by W. Bryn Mawr Ave. and W. Gregory St., and N. California Ave. and N. Washtenaw Ave. The plan view of the study blocks is illustrated in Figure 1. Blocks 1 and 2 have 22 and 28 residential units, and are 1.86 and 1.61 hectares in size, respectively. In block 2, one unusually large multi-family residential unit was excluded. Permission for access to survey individual lots was received from 16 residential units in block

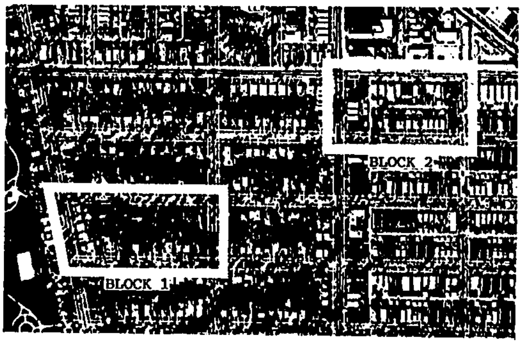

Figure 1. Plan view of study block 1 and block 2.

1(73 percent of total) and 17 residential units in block 2 (61 percent of total).

2. Modeling of energy savings by vegetation

1) Shading effect

A. Introduction of computer programs

The effect of tree shading on savings of building heating and cooling energy was modeled using SPS(McPherson et al., 1985) and MICROPAS(ENERCOMP, Inc., 1992), two computer simulation programs.

SPS(Shadow Pattern Simulator) creates MICROPAS-compatible hourly shading coefficients(from 0.0 to 1.0) for entire building surfaces from the shading of a tree(McPherson et al., 1985 and 1988; McPherson and Rowntree, 1986; McPherson and Dougherty, 1989; McPherson, 1990). The SPS uses sun-tree-building geometry to compute the surface shading coefficients for each specified hour and day. The locations of trees are entered based on an X-Y coordinate system centering at one edge of the building.

MICROPAS is a microcomputer-based building energy simulation program that estimates hour-by-hour building energy use based on the building's thermal characteristics, occupant behavior, and specific weather data (Nittler and Novotny, 1983; McPherson et al., 1988; McPherson and Dougherty, 1989; McPherson, 1990; McPherson and Sacamano, 1992; ENERCOMP, Inc., 1992; McPherson et al., 1993b). When an SPS file is loaded to a MICROPAS file, MICROPAS calculates the amount of building energy use, particularly reflecting the shading effect. The program performs this function by altering solar radiation on building surfaces for energy analysis and calculating hourly and monthly heatflow and zone load energy requirements. A MICROPAS-compatible local weather file(by ENERCOMP) including hourly temperature, radiation and wind speed data is loaded to the MICROPAS to accomplish its simulation.

B. Modeling procedures and methods

Data on dimensions of buildings and the number, size, and location of trees around each building were inventoried in the sample of 33 residential lots to model the shading effects with the two simulation programs. For trees, trunk diameter at 1.3m above the ground level (dbh) and crown diameter were measured using a measuring tape. An altimeter was used to measure total and crown height of trees.

The number, sizes, and locations of trees were highly variable among different residences. Simulating the shading effects of the variable trees on each residential building in the two study blocks would have required a great deal of time and have created large numbers of files. Also, metered energy consumption data to validate modeled energy use were not available for all the residential buildings due to limited permission.

Therefore, an alternative method was determined which could reflect the variability and also reduce the effort and time for modeling. This method was to find out the amount of energy savings from the shading effect per shade tree in various tree sizes, and locations, and then to extrapolate energy savings per tree to other similar shade trees(in terms of size and location) around each residential buildings. Detailed descriptions about this method are as follows:

Representative prototype buildings and tree configurations were created so that they could represent buliding types and tree characteristics in study blocks. Three different building types for each study block were simulated with the SPS program. For study block 1, square buildings of different sizes and numbers of stories were used: 1−story large(15×15m), 2−story small(7.5×7.5m), and 2−story large(15×15m) buildings. For study block 2, rectangular buildings of similar sizes(7.5×15m) but different orientations and numbers of stories were used: 1−story NS orientation, 1−story EW orientation, and 2−story NS orientation buildings. Height of all the buildings was 3m for 1 story and 6m for 2 story. For tree variables of size, distance and direction from building, 42 different input files were considered for each building type. Figure 2 illustrates distance and directional coordinates of shade trees from a building and Table 1 shows the characteristics of the three representative tree sizes. Small and medium trees were located at a distance of 3.6m from building, small, medium and large trees at 6.6m, and only large trees at 10.2m. All the shade trees were assumed to be deciduous, because most of shade trees in study blocks were deciduous(about 95 percent). The trees were assumed to block 85 percent of the available irradiance during the in−leaf period(May to October) and 25 percent of irradiance when leaves were absent(McPherson, 1984; McPherson et al., 1993b).

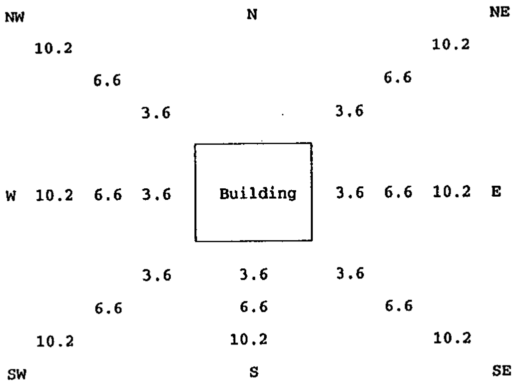

Figure 2. Distance and directional coordinates of trees from residential building. The figures indicate distances from building in meters.

Table 1. Tree characteristics as SPS input data*.

Size(m)	Small	Medium	Large
CD	3.6	7.2	10.8
CH	5.4	8.4	11.4
TH	7.2	10.8	15.0
Shape	P	P	P
SSC	0.15	0.15	0.15
WSC	0.75	0.75	0.75

*CD: Crown diameter, CH: Crown height, TH: Tree height, P: Paraboloid, SSC: Summer Shading coefficient, WSC: Winter shading coefficient.

Six MICROPAS files for each building prototype were prepared using base case building characteristics, as shown in Table 2. Input data were collected from one residential building in each prototype, selected for accessibility for data collection. For heating and cooling intensities, an annual average from buildings of each type was applied to each prototype. Two−year metered energy consumption data(1991 and 1992) for 18 residential units in the study blocks were collected from Commonwealth Edison and Peoples Gas(suppliers of electricity and natural gas, respectively). Modeled energy use was matched to metered energy use in each base case building through model parameterization(through slight adjustment of parameters for which obtainment of accurate data was impossible−for example, efficiencies of heating and cooling systems, thermostat settings, and duct insulation). This was followed by iterative runs of MICROPAS. Forty−two SPS output files were run with each building prototype MICROPAS file to alter solar radiation on building surfaces for an energy analysis of the effects of different sizes, distances and directions of trees. The MICROPAS used a full−year Chicago weather file provided by ENERCOMP to perform hour−by−hour heatflow and zone load energy calculations. A total of 252(42×6) SPS and MICROPAS files were thus created to accomplish the simulation purposes.

Table 2. Base case building characteristics as building energy analysis input data.

Building feature	Block 1			Block 2	
	1story, large	2story, small	2story, large	1 story	2 story
Construction type	Brick	Brick	Brick	Brick	Brick
Date built	1940–1960	1940–1960	1940–1960	1950–1960	1950–1960
No. units/occupants	1/3	1/2	1/4	1/2	2/6
Heat/cool intensity					
Heat(Btu/HDD*sm)	142.73	218.72	190.31	144.34	149.94
Cool(Wh/CDD*sm)	9.90	8.93	11.95	7.86	12.59
Floor area(sm)	197	181	331	132	190
Volume(cu m)	542	496	959	363	521
Floor dimensions(m)	15.96×12.37	8.76×10.33	11.88×13.94	7.59×17.31	7.38×12.88
Front orientation	North	South	South	North	South
Window panes(no. & u)	2, 0.60	2, 0.65	2, 0.65	2, 0.44	2, 0.44
Window area(sm)					
North	7	4	12.	3	3
East	9	5	10	6	8
South	6	7	9	4	7
West	3	6	20	3	6
Total	25	22	51	16	25
% of floor area	12.7	12.0	15.5	11.9	13.0
Window shading coef.					
Glass only	0.88	0.88	0.88	0.88	0.88
Drapes or blinds	0.78	0.78	0.78	0.78	0.78
Duct insulation(R value)					
Duct	4.2	2.0	2.0	4.2	4.2
CVCrawl	4.2	4.2	4.2	4.2	4.2
Wall insulation(R value)	7.1	7.1	7.1	7.1	7.1
Attic insulation	19	19	19	38	38
Crawlspace/basement					
Floor(R value)	4	4	4	8	4
Stem wall(R Value)	5	5	5	5	5
Infiltration (vent ACH)	0.56	0.90	1.11	0.54	0.90
Infil. shielding	3	4	4	3	4
Latent heat fraction	0.1	0.1	0.1	0.1	0.1
Glazing obstruction	0.7	0.7	0.8	0.65	0.7
Wind correction factor	0.25	0.4	0.4	0.25	0.4
Internal gain(Btu/hr)	51,875	49,205	73,430	41,225	70,660
Gas furnace efficiency	0.60	0.55	0.58	0.67	0.60
Air conditioner(SEER)	7.8	8.0	6.7	8.9	6.6
Thermostat settings	No setback	No setback	No setback	No setback	No setback
Summer cooling	78	80	80	79	78
Winter heating	70	72	72	70	70

2) Evapotranspiration and wind-reduction effect

Evapotranspirational (ET) cooling and wind reduction effects result from the aggregate impacts of all neighborhood vegetation, not just the trees directly shading the building. Existing research(Huang et al., 1987; Profous, 1992) reports that a 10 percent increase in vegetation cover decreases summer temperature by 0.6 to 1.1℃. There was a difference of about 20 percent in vegetation cover between the two study blocks(study block 1: 58.9 percent, block 2: 36.3 percent), when all plants including grass were considered. Based on the existing research, it was expected that study block 1 could be at least 1℃ cooler than block 2. To confirm this expectation, temperatures were measured with a portable temperature-measuring instrument at 25 to 30 random spots in each block every 3-hour interval from 5:40 am to 6:20 pm, on a sunny day in the early part of July, 1993. The measurement revealed that temperature in study block 1 was about 1℃ cooler(during noon to midafternoon) than in study block 2(although this measurement might not represent daytime temperatures during whole summer period). Based on these observed temperature differences, summer daytime temperatures in the MICROPAS weather file were lowered to account for evapotranspiration cooling in study block 1. This weather file was run with each base case MICROPAS file to calculate the amount of energy savings attributable to ET cooling in block 1.

A 10-percent increase in tree cover can reduce windspeed by 5 to 15 percent in residential neighborhoods, depending on the housing density(Heisler, 1989 and 1990). MICROPAS uses local shielding classes to incorporate the effects of buildings and vegetation on air infiltration rates in houses. Conservative windspeed reductions of 5 to 10 percent were simulated by modifying the building shielding calss for six base case MICROPAS files, from moderate shielding(i.e., some obstructions within two house heights, thick hedge, solid fence, or one neighboring house) to heavy shielding(i.e., obstructions around most of perimeter, buildings or trees within 9m in most directions) (McPherson et al., 1993b).

III. Results and Discussion

1. Introductory information

1) Climate

The climate of Chicago is a moist moid-continental type with considerable seasonal variation in precipitation and temperature. According to weather data from 1988 to 1992(NOAA, 1993), annual temperature averages about 10℃, and annual precipitation averages about 870mm. Mean monthly temperatures range from −3℃ in December to 23℃ in July. Precipitation is at a maximum in August with 126mm and at a minimum in February with 32mm. Average windspeed is 16.6km/hr, and windiest period is January through April (McPherson et al., 1993a).

2) Vegetation

In the study area, total number of species of trees and shrubs is 34 and 35, respectively, for block 1, and 21 and 24 for block 2. Main species found are maples(*Acer negundo, A. platanoides, A.* saccharinum), elms(*Ulmus americana, U. pumila*), mulberry (*Morus alba*), crabapple(*Malus* spp.), and cherry(*Prunus* spp.) for trees, and yew(*Taxus baccata*), honeysuckle(*Lonicera* spp.), privet(*Ligustrum* sp.), buckthorn(*Rhamnus cathartica, R. frangula*), dogwood(*cornus* spp.), rose(*Rosa* spp.) and juniper(*Juniperus communis*) for shrubs. The number of tree and shrub individuals averages about 119.4 per residential unit in block 1 and 25.5 in block 2.

Analysis of the dbh distribution of trees reveals that the tree population in the study area is quite young. Trees with dbh size of less than 30cm accounts for 80 percent and 90 percent of all trees surveyed in block 1 and block 2, respectively. For shrubs, distributions of diameter at 15−cm above ground level are similar between blocks, with about 80 percent of all shrubs in the 1.1 to 9.0cm diameter size class.

Percentage of tree−shrub cover in block 1 averages about 41.6 percent per residential unit, and mean available growing space(AGS) is 25.7 percent. In this study, AGS is defined as permeable surface areas larger than 2 by 2m in size, not fully shaded by adjacent buildings, and without obstruction from above ground utility lines. Tree−shrub cover in block 2 is 13.1 percent, 3 times lower than that in block 1. While block 2 has low tree−shrub cover, its mean AGS is 22.4 percent per residential unit, implying potential planting area similar to that in block 1. McPherson et al. (1993a) found that average tree cover in residential areas of Chicago ranged from 7 percent for four− or more−family residential lots to 15 percent for one−to three−family residential lots. Compared to their study, block 1 has a high level of tree cover, while block 2 is more characteristic of the city−wide average.

3) Residential buildings

The number of residential buildings for the three prototypes in block 1 is 5 for 1−story large, 7 for 2−story small, and 10 for 2−story large buildings. For study block 2, the building numbers for each prototype are 7 for 1−story NS orientation, 4 for 1−story EW orientation, and 17 for 2-story NS orientation buildings. The front of most residential buildings is oriented to the south or the north due to the subdivision layout. Although one and two story homes occur in both blocks, two story buildings are most common. Floor area ranges from approximately 170m^2 to 470m^2 for block 1(mean=276m^2), and from 75m^2 to 400㎡ for block 2 (mean=200m^2). All the residences inventoried in study block 1 are single family, and the number of occupants ranges from 1 to 4. Study block 2 is composed of 1-4 family residential buildings, with occupant numbers ranging from 2-17 per building.

4) Areal distribution of land cover types

Total lot area ranges from about 583m^2 to 2,428m^2 with an average of 978.9m^2 in study block 1. Lot area ranges from about 308m^2 to 1,146m^2 with mean 503.1m^2 in block 2. The mean lot area is about two times larger in block 1 than in block 2. Percentages per residence of land cover types in block 1 average 37.7 percent for grass, 21.7 percent for building and garage, 18.7 percent for paving, 6.8 percent for soil and mulch, and 15.1 percent for other pervious surfaces. In block 2, the percentages of land cover types average 36.4 percent for building and garage, 26.9 percent for grass, 25.9 percent for paving, 5.6 percent for soil and mulch, and 5.2 percent for other pervious surfaces. While impervious surfaces in block 1 average about 40 percent of lot area, they average 62 percent of lot area in block 2. This reflects the higher building densities in block 2.

2. Effects of vegetation on energy savings

1) Shading effect

Analyses of shading effects by different tree sizes and locations on space conditioning energy use reveal that building cooling and heating energy savings are significantly influenced by size, direction, and distance of shade trees from the buildings. Table 3 summarizes the effects of different tree sizes and locations on average annual energy savings from six building prototypes. A large tree(10.8m in crown diameter) located at a distance of 6.6m from the west or east wall of buildings provides the greatest cooling energy savings, a savings of about 7 to 8 percent. However, most of the existing shade trees increase heating energy use by reducing solar heat gain during winter. Medium and large trees(7.2m or longer in crown diameter) located close to south wall are projected to increase heating energy use by 1 percent. Other studies have found that the greatest cooling saving comes from a tree on the west, whereas a south tree can increase heating energy use (Minnesota Dept. of Natural Resources, 1991; McPherson et al., 1993b).

A large tree located at 6.6m from west walls provides the greatest net annual energy saving with an average of $14.7, as shown in Table 3. The second greatest saving comes from trees of medium size at 3.6m in the same direction. The third greatest saving results from a large tree at 6.6m from east wall and at 10.2m from west wall. While all trees planted on the west and east reduce building energy cost(except small trees at 6.6m on the east), most of other shade trees are negative for energy savings, increasing energy use by a maximum of about $6 per year(a large tree at 6.6m from south wall). All trees located in the NE and NW directions do not show a negative effect on energy savings. Based on the results mentioned above, it is concluded that the best solution for saving building energy through shading is to plant large trees on the west side and close to buildings. Additional energy saving will result from tree planting on the east.

Table 3. Effects of different tree sizes and locations on average annual energy savings for six building prototypes in study blocks.

Shading type			% savings		$ net
Tree size	Direction	Distance*	Heating	Cooling	savings**
Small	NE	3.6	0	0	0
Medium	NE	3.6	-0.03	0.42	0.33
Small	E	3.6	-0.37	2.40	0.69
Medium	E	3.6	-0.61	6.52	6.71
Small	SE	3.6	-0.27	0	-2.66
Medium	SE	3.6	-0.72	1.55	-4.12
Small	S	3.6	-0.38	0.42	-3.01
Medium	S	3.6	-1.02	3.55	-2.95
Small	SW	3.6	-0.10	0	-0.98
Medium	SW	3.6	-0.38	1.75	-0.58
Small	W	3.6	-0.10	1.72	2.59
Medium	W	3.6	-0.27	5.96	10.53
Small	NW	3.6	0	0	0
Medium	NW	3.6	0	0.42	0.63
Small	NE	6.6	0	0	0
Medium	NE	6.6	0	0	0
Large	NE	6.6	-0.02	0.18	0.16
Small	E	6.6	-0.31	1.40	-0.65
Medium	E	6.6	-0.49	4.48	3.58
Large	E	6.6	-0.62	7.93	9.92
Small	SE	6.6	-0.15	0	-1.47
Medium	SE	6.6	-0.48	0	-4.74
Large	SE	6.6	-0.78	0.99	-6.10
Small	S	6.6	-0.13	0	-1.22
Medium	S	6.6	-0.53	0.42	-4.67
Large	S	6.6	-1.03	2.31	-6.05
Small	SW	6.6	-0.04	0	-0.38
Medium	SW	6.6	-0.19	0	-1.89
Large	SW	6.6	-0.42	1.14	-2.08
Small	W	6.6	-0.04	0.77	1.25
Medium	W	6.6	-0.13	3.60	6.39
Large	W	6.6	-0.25	7.26	14.74
Small	NW	6.6	0	0	0
Medium	NW	6.6	-0.01	0.40	0.62
Large	NW	10.2	0	0	0
Large	NE	10.2	0	0	0
Large	E	10.2	-0.49	5.85	6.87
Large	SE	10.2	-0.52	0	-5.04
Large	S	10.2	-0.55	0.42	-4.88
Large	SW	10.2	-0.25	0	-2.53
Large	W	10.2	-0.14	4.71	9.77
Large	NW	10.2	0	0	0

* It indicates distance from wall in meter.

**Negative values mean net increase in total annual energy use due to increase of heating energy use by winter shade more than reduction of cooling energy use by summer shade.

Table 4 shows the effects of all shading trees around each residential building on heating and cooling energy savings in the study blocks. In study block 1, cooling energy saving from shading averages about 7.2 percent per residential unit. But, tree shading causes negative heating energy savings with a mean of −1.2 percent per residence). In block 2, the shading effects are negligible for cooling energy due to absence of trees opposite east and west walls, and negative for heating energy because of street and yard trees to the south of buildings. Peak cooling energy saving is important to utilities becaues peak power is expensive to provide. During peak days when air conditioning loads are greatest, more power is generated with fossil fuels. Average energy saving for peak cooling is about 3.5 percent per residential unit in block 1. In block 2, peak cooling energy saving averages 0.4 percent per residence.

Table 4. Effects of all shading trees on savings of space conditioning energy for residential buildings in study blocks.

Block	Heating (%)	Cooling (%)	Peak cooling(%)*	Total annual saving($)**
1 Mean/residence	1.24	7.18	3.49	9.3
Block total				205.6
2 Mean/residence	0.21	0.63	0.41	0.1
Block total				2.2

*4 pm, July 1.

**Saving of peak cooling energy is not considered.

Total annual energy saving from thecombined heating and cooling energy savings(except saving of peak cooling energy) averages $9.3 per residence, ranging from about $−20.9 to 68.7 in block 1(block total is $205.6). In block 2, the annual energy saving averages about $−0.1 per residence(block total is $−2.2). The increase of annual energy cost(i.e., negative saving) in some residential units results from tree planting in locations where the winter shade increases heating energy use more than the summer shade reduces cooling energy use. Also, heating degree days per year are about 6.7 times more than cooling degree days in Chicago. Trees used in simulations of the shading effects were all deciduous. Conifers, which do not shed their leaves during winter, may cause more negative effects on heating energy savings. The total annual energy savings may be greater in the climate regions in which the cooling season is longer.

2) Evapotranspiration effect

Table 5 includes the effect of evapotranspiration(ET) on savings of space conditioning energy in block 1. ET is projected to provide a 7 to 8 percent saving in cooling energy for the residential buildings in study block 1, assuming that the MICROPAS weather file based on weather conditions at Chicago O'Hare Airport applies to the conditions in block 2(for block 1, the weather file was modified by relative maximum decrease of 1℃ in summer daytime temperatures to account for ET cooling). There is no ET effect on heating energy. For peak cooling energy, the saving is estimated to be about 5 to 6 percent. Total annual energy saving attributed to ET cooling effect is about $546.6 in block 1.

Table 5. Effect of evapotranspiration on savings of space conditioning energy for three types of residential buildings in study block 1.

Type	1 story, large	2story, small	2 story, large	Total
Heating(%)	0	0	0	
Cooling(%)	7.61	8.43	7.21	
Peak cooling(%)*	5.95	6.22	5.14	
Total($)**	107.0	110.1	329.5	546.6

* 4 pm, July 1.

** Saving of peak cooling energy is not considered.

3) Windspeed reduction effect

Table 6 shows projected effect of windspeed reduction on savings of space conditioning energy. Energy saving from windspeed redution is about 4 percent for heating, 1 percent for cooling, and 2 percent for peak cooling in 1 story, large residential buildings of block 1. For 1 story buildings in block 2, the heating and cooling energy savings are similar to those in block 1. In both blocks, no saving from windspeed reduction is projected for 2 story buildings due to little wind shielding for the second floor(low vegetation density in the upper layer). Total annual energy saving attributed to windspeed reduction is $266.4 in block 1 and $ 242.7 in block 2.

4) Aggregate effects of shading, evapotranspiration and windspeed-reduction

Figure 3 displays aggregate effects of shading, ET and windspeed-reduction in each study block. Aggregate annual energy saving is projected to be approximately $1,018.6 in study block 1 and $240.5 in block 2. The aggregate an-

Table 6. Projected effect of windspeed reduction onsavings of space conditioning energy for each prototype building.

Block	1				2			
Type	1 story large	2 story small	2 story large	Total	1 story NS	1 story EW	2 story	Total
Heating(%)	4.45	0	0		3.95	3.91	0	
Cooling(%)	1.11	0	0		1.38	1.44	0	
Peak cooling(%)*	2.14	0	0		2.05	1.63	0	
Total($)**	266.4	0	0	266.4	161.6	81.1	0	242.7

* 4 pm, July 1.

** Saving of peak cooling energy is not considered.

nual energy saving averages $46.3 per residence in block 1 and $8.6 per residence in block 2.

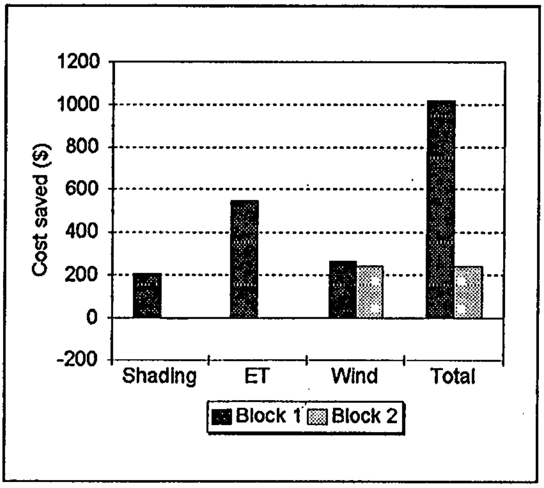

Figure 3. Aggregate effects of shading, evapotranspiration and wind reduction on energy savings in study blocks.

3. Planting guidelines

1) Planting in the west

The best place to locate trees for maximizing energy savings is opposite west facing windows and walls. Planting in this direction will obstruct solar gain in the afternoon during summer. Trees of various sizes can be planted, densely if possible, but the trees should be located close to the wall for efficient shading.

2) Planting of large trees in the east

Planting of medium or large trees in the east blocks solar gain in the morning and reduces air conditioning demand during the summer. But, avoid planting small trees or shrubs, especially evergreens. They have adverse effects on overall energy savings by hindering solar gain early in the winter morning.

3) Avoidance of planting in the south

Trees located in the south, southeast, and southwest cause net increase in annual energy cost. They increase the demand of heating energy during the winter season through solar gain obstruction, particularly in Chicago which has much greater heating degree days than cooling degree days. Only shrub planting along the south boundary of yards is allowed. If residents desire to plant trees in the soth, solar−friendly trees(i.e., deciduous trees that possess relatively open crowns when out of leaf, leaf out late in spring, and that drop their leaves early in fall) should be selected here(e.g., honeylocust).

4) Dense planting in the north

Full plantings in the north, northeast, and northwest are recommended to maximize annual energy savings through windspeed−reduction and evapotranspiration effects in the neighborhood. The use of evergreen shrubs or hedges on north walls will reduce heat conduction from, and cold−wind infiltration to the interior of buildings.

5) Reduction of impervious surfaces

The present impervious surfaces should be decreased to improve tree plantings. In study block 2, there is little planting space for street trees along Byrn Mawr Avenue due to the wide sidewalk. Reducing impervious cement areas in back yards also will result in increased space for tree planting.

6) Relocation of above ground utility lines

The above ground utility lines in the middle of back yards should be relocated to the boundary of the yards or below ground. Utility lines significantly obstruct tree plantings, based on the author's field survey.

Ⅳ. Conclusion

This study was conducted to suggest proper planting guidelines to save home cooling and heating energy. The study quantified shading, evapotranspiration, and windspeed-reduction effects of existing vegetation on energy use of residential neighborhoods in Chicago. For purposes of detailed quantification, the scale of this study was limited to two residential blocks (22 residential units in block 1, and 28 in block 2) having a significant difference in vegetation cover. The study area is located in northwest Chicago, U.S.A.

Aggregate annual energy saving from tree plantings was projected to be approximately $1,018.6 in study block 1(ET: 53.7%, wind reduction: 26.1%, shading: 20.2%) and $240.5 in block 2. The aggregate annual energy saving averaged $ 46.3 per residence on block 1 and $ 8.6 per residence in block 2. The annual energy saving was greater in residential neighborhood with higher vegetation cover. This annual saving may increase as trees grow. However, some trees located at the wrong locations caused negative net shading effects(a maximum of $6 per tree) due to decreased solar gain during winter.

The best solution for maximizing the shading effects is to plant large trees close to the west or east wall of buildings. Tree plantings close to the south wall should be avoided(except solar-friendly trees). Full plantings in the north, northeast, and northwest are recommended to maximize windspeed-reduction and evapotranspiration effects in the neighborhood.

The results of this study could be applied to the middle regions of Korea similar to Chicago in weather pattern. The study will contribute not merely to increasing home energy saving through tree plantings, but also to decreasing emissons of air pollutants through reduction of fossil fuel consumption for cooling and heating.

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References

1. DeWalle, D. R. (1987) "Manipulation urban vegetation for residential energy conservation", In *Proceedings of National Urban Forestry Conference*, ESF Pub. 80-003. Syracuse, NY : SUNY. pp. 267-283.
2. DeWalle, D. R., G. M. Heisler, and R. E. Jacobs(1983) "Forest home sites influence heating and cooling energy", *Journal of Forestry*, 8: 84-88.
3. ENERCOMP (Energy Engineering & Microcomputer Applications), Inc. (1992) *MICROPAS4 User's Manual Sacramento*, CA.
4. Heisler, G. M.(1989) *Site Design and Microclimate Research* (final report to Argonne National Laboratory), University Park, PA: USDA Forest Serrvice, Northeast Forest Exeriment Station.
5. Heisler, G. M. (1990) "Mean wind speed below building height in residential neighborhoods with different tree densities", *ASHRAE Transactions*, 96: 1389-1396.
6. Heisler, G. M. (1991) "Computer simultion for optimizing windbreak placement to save energy for heating and cooling buildings", In *Trees and Sustainable Development* (June 27), Ridgetown, Ontario, Canada: Ridgetown College. pp. 100-104.
7. Huang, Y. J., H. Akbari, H. Taha, and A. H. Rosenfeld (1987) "The potential of vegetation in reducing summer cooling loads in residential buildings", *Journal of Climate and Applied Meteorology*, 26: 1103-1116.
8. Huang, J., R. Ritschard, N. Sampson, and H. Taha (1992)

"The benefits of urban trees", In Akbari, H., S. Davis, S. Dorsano, J. Huang, and S. Winnett, eds.,*Cooling our Communities.* Washington, D. C. : U.S. Environmental Protection Agency. pp. 27−42.

9. McPherson, E. G. (1984) "Planting design for solar control", In McPherson, E. G., ed., *Energy−Conserving Site Design,* Washington, D.C. : ASLA. pp. 141−164.

10. McPherson, E. G. (1990) "Modeling residential landscape energy and water use to evaluate water conservation policies", *Landscape Journal,* 9(2) : 122−134.

11. McPherson, E. G., D. J. Nowak, and P. L. Sacamano, S. E. Prichard, and E. M. Makra (1993a) *Chicago's Evolving Urban Forest : Initial Report of the Chicago Urban Forest Climate Project,* General Technical Report NE−169. Radnor, PA : USDA Forest Service, Northeastern Forest Experiment Station.

12. McPherson, E. G., and E. Dougherty (1989) "Selecting trees for shade in the Southwest", *Journal of Arboriculture,* 15(2) : 35−43.

13. McPherson, E. G., L. P. Herrington, and G. M. Heisler (1988) "Impacts of vegetation on residential heating and cooling", *Energy and buildings,* 12 : 41−51.

14. McPherson, E. G., and P. L. Sacamano (1992) *Energy Savings with Trees in Southern California,* Final Report to Southern California Edison.

15. McPherson, E. G., P. L. Sacamano, S. Wensman, J. Ratliff, and H. K. Jo (1993b) *Modeling Benefits and Costs of Community Tree Plantings: A Demonstration Project,* Final Report to USDA Foest Service.

16. McPherson, E. G., and R. A. Rowntree (1986) "Tree shade", *Landscape Architecture,* 76(3) : 88−91.

17. McPherson, E. G., and R. A. Rowntree (1988) "Geometric solids for simulation of tree crowns", *Landscape and Urban Planning,* 15 : 79−84.

18. McPherson, E. G., R. Brown, and R. A. Rowntree (1985) "Simulating tree shadow patterns for building energy analysis", In Wilson, A. T., and W. Glennie, eds., *Solar 85−Proceedings of the National Passive Solar Conference.* Boulder, CO : American Solar Energy Society. pp. 378−382.

19. Miller, R. W. (1988) *Urban Forestry,* New Jersey : Prentice Hall, Inc.

20. Minnesota Department of Natural Resources (1991) *Carbon Dioxide Budgets in Minnesota and Recommendations on Reducing Net Emissions with Trees,* Report to the Minnesota Legislature.

21. Nittler, K. B., and R. E. Novotny (1983) "MICROPAS, an annual hourly heating and cooling building simulation for microcomputers", In American Solar Energy Society, Inc., ed., *Progress in Passive Solar Energy Systems,* Boulder, CO.

22. NOAA (National Oceanic and Atmospheric Administration) (1993) *Local Climatological Data* (Monthly Summary).

23. Parker, J. H. (1983) "Do energy Conserving landscapes work?", *Landscape Architecture,* July : 89−90.

24. Parker, J. H. (1989) "The impact of vegetation on air conditioning comsumption", In Garbesi, K., H. Akbari, and P. Martien, eds., *Proceedings of the Workshop on Saving Energy and Reducing Atmospheric Pollution by Controlling Summer Heat Islands,* Berkeley, CA : Lawrence Berkeley Laboratory, University of California. pp. 45−51.

25. Profous, G. V. (1992) "Trees and urban forestry in Beijing, China", *Journal of Arboriculture,* 18 : 145−153.

26. Sampson, R. N., G. A Moll, and J. J. Kielbaso (1992) "Opportunities to increase urban forests and the potential impacts on carbon storage and conservation", In Sampson, R. N., and D. Hair, eds., *Forests and Global Change* (Volume 1), Washington, D. C. : An American Forests Publication. pp. 51−72.

27. Simpson, J. R., and E. G. McPherson (1993) *Impact of Urban Heat Island on Cooling and Environment : A Demonstration Project,* Public Technology, Inc., Washington, D. C.

28. U. S. Department of Energy, Energy Information Administration (1985) *Annual Energy Outlook−1984 : With Projections to 1995,* Washington, D. C.