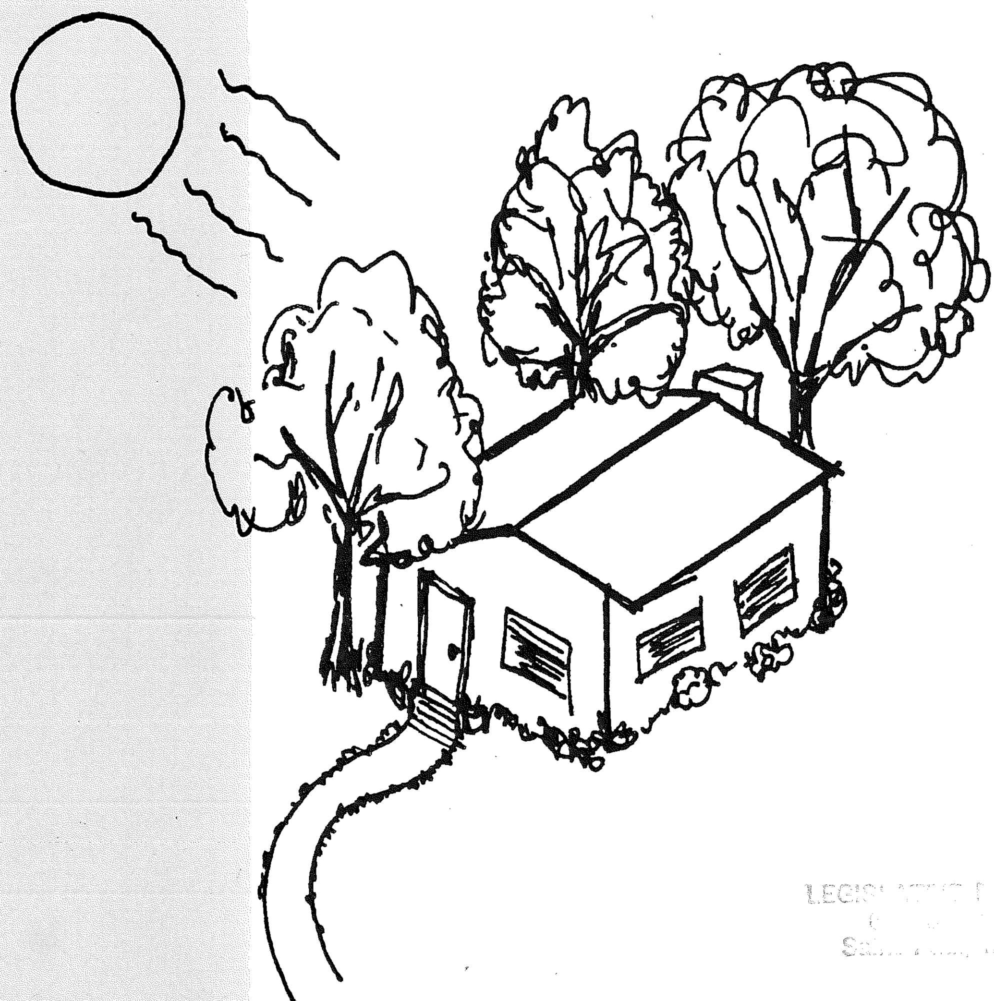
CARBON DIOXIDE BUDGETS IN MINNESOTA AND RECOMMENDATIONS ON REDUCING NET EMISSIONS WITH TREES



REPORT TO THE MINNESOTA LEGISLATURE

MINNESOTA DEPARTMENT OF NATURAL RESOURCES
DIVISION OF FORESTRY, ST. PAUL, MINNESOTA

CARBON DIOXIDE BUDGETS IN MINNESOTA AND RECOMMENDATIONS ON REDUCING NET EMISSIONS WITH TREES

REPORT TO THE MINNESOTA LEGISLATURE

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EXECUTIVE SUMMARY

A study was undertaken to evaluate the feasibility of using trees and other vegetation to reduce net emissions of carbon dioxide to the atmosphere. The basic components of the study were as follows:

1) Quantify releases of carbon dioxide to the atmosphere as a direct result of human activities in Minnesota.

2) Quantify the organic carbon pools in Minnesota.

3) Estimate the amounts of carbon fixed or sequestered by shade trees, shrubs and forest land in Minnesota.

4) Examine the economic benefits of tree planting in reducing utility costs and energy demand.

5) Develop guidelines for tree planting for energy conservation in Minnesota.

6) Develop a proposal for a rural and urban tree planting program to maximize energy conservation benefits and sequestration of carbon.

7) Identify an appropriate fee structure on sources of carbon dioxide to support tree planting efforts for energy conservation and provide incentives for reducing emissions of carbon dioxide.

The major conclusions from this study were:

- An estimated 24.4 million tons of carbon (89.5 million tons of CO_2) were released into the atmosphere within Minnesota in 1988 as a result of human activities. The electrical/steam generation sector and transportation sector each accounted for about one-third of releases of CO_2 from fossil fuel to the atmosphere.

- Two-thirds of the organic carbon in Minnesota is contained in soil, mineral wetlands, and peat. Peat, by itself, contains 37 percent of total organic carbon. Tree biomass contains about 3 percent of total stored organic carbon.

- Forests are a significant storage pool for carbon. As much as 10 percent of the CO_2 emissions are currently removed by increases in total forest biomass. Managed forest land will always fix or sequester more carbon than unmanaged forest land, but net increases in carbon storage also depend on rotation length and other factors.

- Tree planting for the purpose of sequestering carbon will be limited by the availability of land. However, sequestering carbon could be an important component of a total program to reduce releases of CO_2 into the atmosphere, in particular if combined with energy conservation efforts.

- For all locations, building orientations and planting schemes evaluated in this report, tree planting reduces the net amount of CO_2 released to the atmosphere. Reductions in total emissions over 40 years ranged from 1/10 ton to 3 tons per house.

- Strategic tree planting will reduce energy demand for both the individual homeowner and communities.

- The effects of tree shading on utility costs and energy conservation are distinctly different between the northern part and southern half of Minnesota. When only shading effects are considered, no utility savings are likely for houses in the northern part of the state. For the southern half of the state, annual utility costs will be consistently lower when trees are strategically planted.

- In the southern half of Minnesota, tree planting for energy conservation is often a good investment. Smaller trees ($40) pay for themselves in most situations. Larger, more expansive trees ($120) only pay for themselves when the alternative rate of return on the investment is very low.

- The study did not quantify the impact of tree planting on wind reduction and on lowering summer temperatures of urban heat islands. However, a thorough review of other studies indicates that shading likely represents only 10 to 30 percent of the energy benefit expected from trees. Other benefits will result from reductions in wind and reductions in summer temperatures of urban heat islands.

From these conclusions, the following recommendations are made for consideration by the legislature:

- The impact on the carbon balance should be considered in strategies and policies affecting wetlands and peatlands.

- The state should evaluate the merits of minimizing net losses of forested land, particularly where losses of forested land would increase summer temperature and, hence, use of air conditioning.

- Guidelines, policies, and incentives programs should be developed by the state to reduce the number of trees removed or damaged during construction in urban areas.

- The state should set a goal of achieving 50 percent or more tree cover throughout communities in Minnesota.
- The state should develop educational materials and an outreach program to inform the public, local decision makers, and forestry and landscape professionals about strategic energy conservation programs. These materials should be developed from the planting guidelines contained in the report.

- The state should support the establishment of a "MINNESOTA RELEAF" program to promote tree planting in the state. "MINNESOTA RELEAF" would be an organizing vehicle for communities and volunteer action in tree planting and tree care programs.

- The state agencies charged with preparing this report recommend that a $13.5 million annual tree planting program be established, with $8 million targeted for the urban areas and $5.5 million for the rural areas. A surcharge of 15 cents per ton of CO_2 released to the atmosphere is recommended to be levied on each of the primary fuel use sectors based on the amount of the emissions contributed by each of these sectors. Transportation and the electric utilities would each contribute about one-third of the total funding, with the rest to be collected from the residential, industrial, commercial, and agricultural sectors.

- For the rural areas, the tree planting program should be coordinated with existing federal and state programs by piggy-backing new funds with existing cost-share programs. Planting trees which reduce energy use by buildings would have a high priority in rural areas.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES

I. INTRODUCTION

The 1990 Minnesota Legislature clearly stated its concerns over waste carbon dioxide emissions under Minnesota Statutes 116.86 which reads "The legislature recognizes that waste carbon dioxide emissions, primarily from transportation and industrial sources, may be a primary component of the global greenhouse effect that warms the earth's atmosphere and may result in damage to the agricultural, forest, and wildlife resources of the state. The legislature further recognizes that trees are a major factor in keeping the earth's carbon cycle balanced, and planting trees and perennial shrubs and vines recycles carbon downward from the atmosphere."

This concern was the focus for the legislature's charge to the Commissioner of Natural Resources and the Commissioner of the Pollution Control Agency under Laws of Minnesota Chapter 587 Section 2 "to prepare a report on carbon dioxide emissions and incentives to reduce emissions." The study was to address four major points:

1. the development of an appropriate fee structure on carbon dioxide emissions;
2. identifying methods of encouraging tree and perennial shrubs and vine planting to be implemented in lieu of payment of part or all of a surcharge;
3. development of strategic planting guidelines for trees and perennial shrubs and vines;
4. identify and recommend programs to promote youth and community group participation in tree planting efforts.

This report is the Department of Natural Resources and the Pollution Control Agency's effort to fulfill the charge of the legislature. The breadth of the report was constrained by two major factors: 1) a January 1, 1991 report deadline, and 2) limited funding to explore the relationships between perennial vegetation establishment and reductions in carbon dioxide emissions. In particular, the study was limited by the inability to investigate both the impact of tree cover on reducing home heating losses due to wind effects and the effect of trees on reducing summer air temperatures of urban heat islands.

The report was a collaborative effort between the Department of Natural Resources, Pollution Control Agency, Department of Transportation, Department of Public Service, Northern States Power, Minnesota Power and Light, Minnesota Legislature, Minnesota Petroleum Council, University of Minnesota, and Project Environment Foundation. Additional support was provided by the Department of Revenue. The report identifies and quantifies the major sources of carbon dioxide emissions from human activity in Minnesota, and provides an estimate of the major storage pools of organic carbon in Minnesota. It explores the economics, strategy, and feasibility of reducing energy demands as well as sequestering carbon dioxide within the woody tissue of trees. The report documents the feasibility of using trees to reduce the waste emissions of carbon dioxide and provides recommendations on funding and implementing rural and urban programs to accomplish that goal.

II. BACKGROUND

A. Global Impacts

Increasing atmospheric concentrations of carbon dioxide (CO_2) and other "greenhouse gases" has prompted an intense and important environmental debate of global significance. Much of the world scientific opinion supports the view that air pollution brought about by human activities is causing significant warming to the earth's climate. The major stimulus for much of the debate and concern is the universal nature of the impact. The effects of global warming will be long term, global in magnitude and largely irreversible (Davies 1990). There are few who would argue that the increasing concentration of CO_2 is not a serious problem that needs to be addressed. Concern about rising concentrations of CO_2 in the atmosphere has increased interest in the potential for trees to help mitigate the effects of global warming.

B. Role of CO_2 in Global Warming

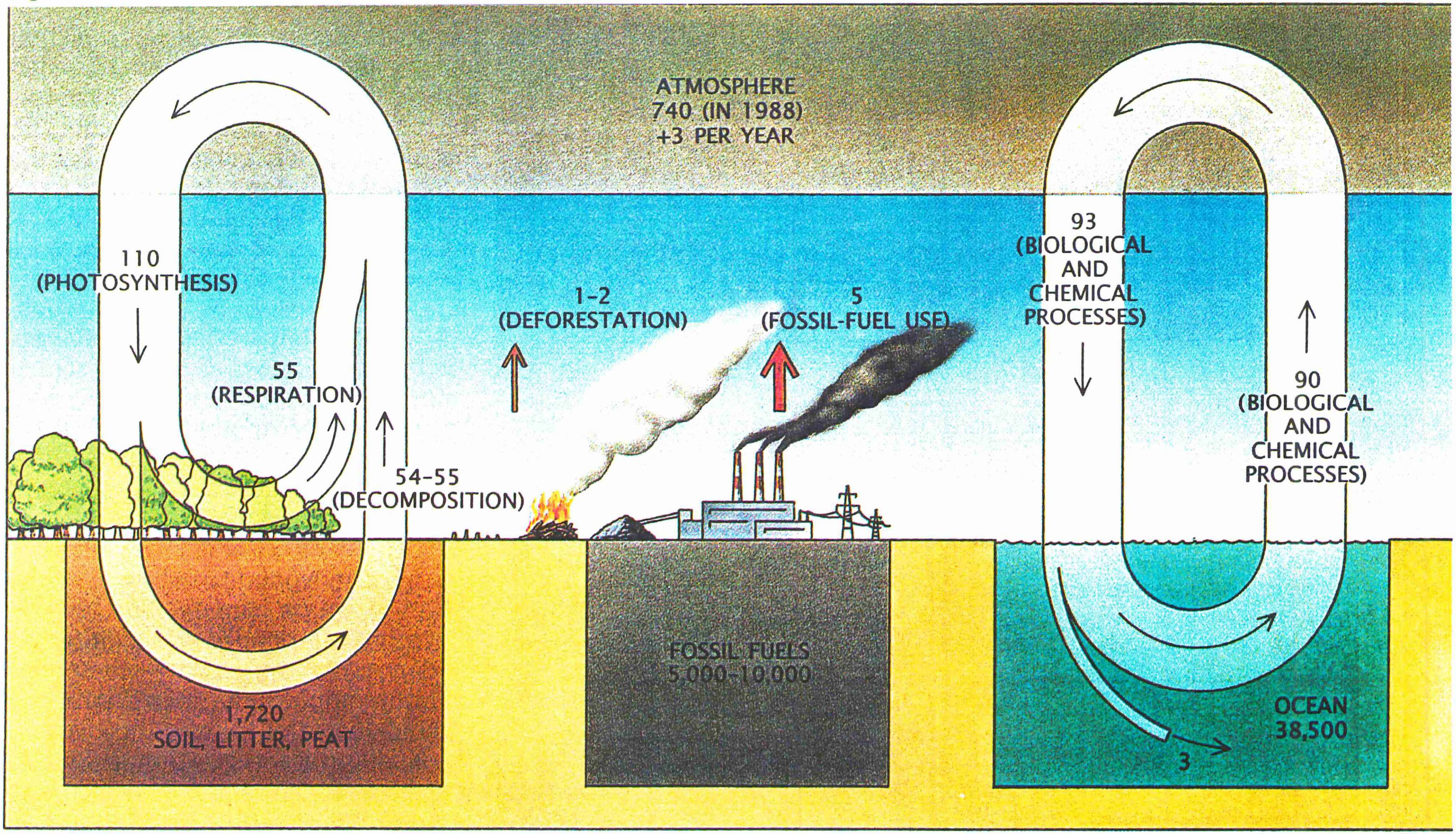
Carbon dioxide currently contributes about half of the total greenhouse effect (Rodhe 1990). The remainder is accounted for by methane, freons, and other gases. The concentration of CO_2 in the earth's atmosphere is currently 351 ppm (Post *et al.* 1989), a 30 percent increase over the preindustrial level of 280 ppm. If current trends of CO_2 emissions continue, the concentration of CO_2 in the earth's atmosphere is expected to double by late in the 21st century (Abrahamson 1989, Schneider 1989). This could result in mean global air temperature increases of between 2.5^{0}F to 8.0^{0}F (Hansen *et al.* 1988, Manabe and Wetherald 1987, Schlesinger and Zhao 1989, Washington and Meehl 1989, Wilson and Mitchell 1987). Once in the atmosphere CO_2 leaves very slowly. If all anthropogenic emissions of CO_2 were suddenly stopped, it would take 200 to 300 years before concentrations returned to pre-industrial levels (Graedel and Crutzen 1989). Existing climate models cannot predict climate change by region. However, current thinking is that the temperature will increase more in interior continental areas, such as Minnesota, than in the world as a whole (Manale and Wetherald 1987).

C. Global Carbon Cycle

Annual fluxes between the major storage pools of carbon are shown in Figure 2.1. There are two major cycles, one on land and one in the oceans. Prior to industrialization, the atmospheric CO_2 level was reasonably stable on time periods of hundreds to thousands of years. Carbon was continuously exchanged between the major carbon reservoirs of the earth, but with little or no observable change in atmospheric levels of CO_2.

With industrialization and use of fossil fuels, carbon long stored within the earth and out of circulation for millions of years was burned and converted to CO_2, leading to large accumulations of atmospheric carbon. On land, plants removed an amount of carbon from the atmosphere that was about equal to the amount released by respiration and decomposition of dead wood and other materials. This balance has been upset by

Figure 2.1. Annual fluxes of carbon in the form of carbon dioxide



CARBON IS EXCHANGED between the atmosphere and reservoirs on the earth. The numbers give the approximate annual fluxes of carbon (in the form of carbon dioxide) and the approximate amount stored in each reservoir in billions of metric tons. The existing cycles—one on land and the other in the oceans—remove about as much carbon from the atmosphere as they add, but human activity (deforestation and fossil-fuel burning) is currently increasing atmospheric carbon by some three billion metric tons yearly. The numbers are based on work by Bert Bolin of the University of Stockholm.

deforesting large areas, so that carbon formerly removed from the atmosphere and stored in the vegetation is added to the atmosphere.

In the oceans, CO_2 is dissolved in seawater. There is a constant exchange between dissolved CO_2 and atmospheric CO_2. Currently, the oceans are taking up slightly more CO_2 than they release annually (3 billion tons, see Figure 2.1). However, this is only about half the amount released into the atmosphere by human activity (6 to 7 billion tons), so that a net increase in CO_2 of about three billion tons is released to the atmosphere each year.

D. Relationship of Trees and Other Vegetation to CO_2

Atmospheric CO_2 enters trees and other plants through pores on the surface of leaves. Inside the leaf the CO_2 is combined with water and converted into cellulose, sugars, and other plant materials in a chemical reaction (photosynthesis) catalyzed by sunlight. Some of these materials are respired back to CO_2 by the tree or used to make leaves which are later shed (Larcher 1980). The remainder is converted to wood, which is about 48 percent carbon by dry weight (Reichle *et al.* 1973). When wood decays or is burned, the carbon it contains is returned to the atmosphere in the form of CO_2.

Newly planted rural forests accumulate carbon for most of their lifespan. Accumulation is rapid for several decades (Alban *et al.* 1978, Harmon *et al.* 1990), and then the annual increase of sequestered carbon declines (Bormann and Likens 1979). When many forests reach the old-growth stage, the amount of carbon released to the atmosphere from the decay of dying trees each year equals the amount sequestered by new growth (Bormann and Likens 1979). Total carbon storage on a per acre basis then remains at an equilibrium until the forest is logged or disturbed by a windstorm or fire.

E. Planting for Energy Conservation

To the extent that the trees and other vegetation shelter buildings and modify the local climate, they are effective in reducing consumption of fuel for heating and cooling buildings. With this reduction in burning fuel comes a reduction in carbon dioxide emissions. This indirect effect of trees on carbon dioxide is so important, that some researchers have predicted that urban trees planted in very large quantities are potentially fifteen times more valuable in reducing carbon dioxide than the same trees planted in the countryside (Akbari *et al.* 1988).

1. *Effect of the Environment on Energy Use in Buildings*

An understanding of the basic ways in which environmental factors, particularly solar radiation and wind, and lifestyles affect energy use in buildings is important. The main effect of solar radiation on building energy use is the solar gain which directly enters through windows, and to a lesser extent through insulated walls and roofs. Even a conventional home in a northern climate derives as much as one third of the heat input during the heating season from the sun (Heisler 1986b). Since roofs are typically better insulated in dwellings

in cold climates, solar gain and shade on the roof is considered less significant for cold climates than is solar gain and shade of windows and exposed areas of walls.

As the sun heats the surrounding air during the warmer months of the year, this heat can be conducted directly through building windows and the less-insulated walls. Because outdoor heat builds gradually through the day and a two to three hour time lag typically exists before heat energy outside transfers inside, overheating tends to occur in the late afternoon (McPherson 1984). People indoors face the most discomfort at this time of day and are most likely to turn towards air conditioning.

The resulting high demand for summer air conditioning in late afternoon overlaps with Americans' tendency to come home from school and work and turn on televisions, microwaves, and other appliances. Thus, peak demand for electricity occurs in late afternoon on the hottest days of the year (Northern States Power 1990). For many electrical utilities and the consumers who pay their bills, not only does this peak power usage directly cost more, but it is a primary reason for construction of new power plants which raises cost for all electricity. Thus, for much of the country and for utilities such as Northern States Power, a high priority in saving energy is to reduce peak loads.

Wind also impacts energy consumption in buildings. The stronger the wind and the leakier the building, the more the outside air will blow in and replace the inside air through the process of air exchange (sometimes called air infiltration). This effect is most pronounced when the difference between indoor and outdoor temperatures are the greatest. Thus, when it is very cold outside in winter, the impact of wind is most severe. In winter, air exchange causes from one-third to over one-half of the heat loss from homes (Dewalle and Heisler 1988).

Conversely, in the summer when indoor-outdoor temperature differences in this climate are not as extreme, wind is less of a factor. However, where natural ventilation is the means of summer cooling, care should be taken not to block these breezes.

2. *Influence of Climate on the Heating-Cooling Balance*

Climatic conditions strongly influence energy consumption patterns and conservation potentials, particularly in a climate with temperature extremes like Minnesota. Because of fuels being burned and the number of structures, the air temperature in a metropolitan area typically will be higher than the surrounding countryside causing the "urban heat island". These "urban heat islands" are most likely to occur in metropolitan areas exceeding 100,000 in population (Karl *et al.* 1988). In cities, incoming solar radiation increases the air temperature and warms buildings and road surfaces, thus adding to the "urban heat island." This effect is modifed to a degree by trees and other vegetation through the process of evapotranspiration (ET). Through ET, energy is used to evaporate water into the air rather than heat the air. This later property is considered to be the most important way trees can contribute to energy conservation (Akbari, Huang, McPherson). The long term warming of cities due to the heat island effect is directly related to increases in peak electric loads, with each °F increase in temperature responsible for a 1 to 2 percent increase in peak cooling loads (Akbari *et al.* 1990).

A review of climatic data for Minnesota indicates a wide range of needs for air conditioning. Days in which the average daily temperature is over 65°F, ranges from zero days (near Lake Superior) to over 90 days (Twin Cities and southern parts of the state) (Baker *et al.* 1985). Thus, the reasons for using shade trees differ from being a substitute for air conditioning to reducing costs for running air conditioners. Therefore, planting strategies are likely to vary across the state.

Though most of the attention in building energy conservation focuses on air conditioning, it is apparent that Minnesotans live in an environment dominated by the need to heat buildings. This is particularly important for a single family home resident who typically spends several times more on heating than on cooling even in a fully air conditioned home. In northern Minnesota, cooling costs are only a fraction of annual heating costs. Cooling becomes a more important factor in central and southern Minnesota. The high heating-cooling ratios mean that Minnesota energy conservation practices need to account for annual energy savings which combine changes in heating and cooling loads. Specific understanding is needed of what actions can cost more in heating fuel than they save in cooling reductions.

3. *Influence of Trees on the Environment and Energy Use*

Trees and other vegetation impact energy use and conservation in several important ways. Trees block solar radiation and reduce solar gain through building windows and on air conditioning units. Mature open-grown deciduous trees can block an average of 70 to 90 percent of the solar radiation on clear days in summer (McPherson 1984). However, deciduous trees have a significant shading impact in winter. Branches and twigs of bare trees block 20 to 55 percent of the solar radiation passing through them in winter. Because the sun angle is low and nearly perpendicular to walls and windows, winter insolation on walls and windows is important. In fact, because of low solar angles and reflectivity off ground snow, solar energy reaching a south facade can be greater in winter than summer, and reductions in solar energy by a leafless deciduous tree on clear winter days can be larger than those produced by the same tree on a clear summer day (Heisler 1986b).

The most obvious plant characteristics of importance in energy conservation are the height, form, and crown density of the plants. An important tree characteristic is crown density and is directly related to the amount of solar radiation blockage by leaf and branch structure. Crown density differs between species and becomes more dense as a tree grows older. A less obvious but important plant characteristic is its foliation period which is the timing of when a plant leafs out and drops its leaves. The foliation period is not only species dependent, but variable within species depending on the weather, growing conditions, and the origins of plant. Ideally for any location, the most beneficial plant species will have high ratios of summer to winter density and inleaf seasons that coincide with the demand for air conditioning (Heisler 1990a).

A primary goal in using vegetation for energy conservation is to maximize shade during the cooling season and minimize shade during the heating season. For homes and small commercial and institutional buildings, Minnesotans should maximize shade on windows during the cooling season at the times of day of greatest solar gain, without decreasing solar gain during the heating season through windows when they receive the most intense sun. Furthermore, strategic planting to reduce peak loads is particularly effective since trees planted to block the late afternoon sun are less likely to create winter shading problems when the sun is further south. The implications of these statements is that the particular location and branching height of trees used will effect their potential for energy conservation. Plants located on the west will be more advantageous than ones located on the south (Heisler 1986a).

In addition to providing shade, trees act as "evaporative coolers" by dissipating incoming solar energy through evapotranspiration processes (Huang *et al.* 1987). As much as 70 to 80 percent of the energy conservation benefit of trees may be attributed to reductions in urban heat island through the evapotranspiration effects of trees (Huang *et al.* 1987, McPherson 1990). A computer simulation developed for Minneapolis at the Lawrence Berkeley Laboratory predicts that direct shading of buildings only accounts for 10 to 30 percent of the projected reduction in air conditioning demands (Huang *et al.* 1987). The majority of the projected benefit of planting large numbers of trees comes from the magnitude of the collective evapotranspiration of trees which they predict would lower the summer air temperature enough to eliminate the urban heat island.

Trees also impact energy use and conservation by reducing wind speed. Rows of trees can reduce wind speed by up to about 85 percent (Heisler 1990a), and lower annual energy costs for home heating 15 to 25 percent in the north central U.S. (Dewalle and Heisler 1988). Windbreaks function to save energy in part by reducing building air exchange. Studies suggest that properly planted windbreaks can reduce annual heating costs by as much as 9 to 11 percent (Huang *et al.* 1990, McPherson *et al.* 1988).

Windbreaks are projected to be most effective on urban sites when placed upwind about two times the height of the house, depending on balancing needs for solar access, wind buffering, and snow drift control (DeWalle and Heisler 1988). For most of Minnesota, windbreaks should be strategically located to maximize protection for any windows and doors oriented towards the prevailing northwesterly winter winds. Trees selected for windbreaks should be dense, relatively stiff, reasonably fast growing and tend to keep their branches to the ground. Among the species suggested are Norway spruce, white pine, and Colorado spruce (Heisler 1986c).

4. *Planting Effectiveness*

Much of the work on the use of plants for energy conservation assumes that the plants grow vigorously and perform well. Yet, the very locations most needing vegetative climate modification - hot and windswept sites - may be least conducive to plant vigor. In Minnesota, the potential for drought and the climatically limited growing season may impact plant growth and vigor and their subsequent potential effectiveness for energy conservation over time. Such limitations are particularly problematic since the assumption with energy conservation plantings is that the plants have enough size and substance to be effective, yet with enough strength and longevity to be appropriate planted near structures. Plant performance may become even more critical in looking at cost effectiveness for energy conservation plantings in Minnesota. Plant costs in Minnesota are higher, while growth rates (i.e. time needed for return on investment) may be substantially longer, than those presumed in studies done elsewhere.

The greatest benefit in the shortest payback period are large, healthy trees, strategically located. Thus, efforts to preserve trees and encourage proper placement of buildings near existing trees may best maximize the plants' immediate and ongoing energy conservation potential.

III. PRODUCTION OF CARBON DIOXIDE AND CARBON STORAGE IN MINNESOTA

CONCLUSIONS

* Largescale combustion activities in 1988 within Minnesota resulted in the production and release to the atmosphere of an estimated 24.4 million tons of carbon. This amounts to roughly two percent of total U.S. combustion emissions, and less than half a percent of global combustion emissions of CO_2.

* Within Minnesota, the electrical/steam generation and transportation sectors are the two largest emitting fuel use sectors, accounting for about two-thirds of all releases of CO_2 from fuel to the atmosphere.

* Among fuel type, coal and refined petroleum products are the largest combustion sources of CO_2, accounting for about 78 percent of statewide emissions of CO_2. The combustion of gasoline in cars and light trucks is the single largest petroleum source of carbon emissions, accounting for roughly one-quarter of Minnesota production and release of CO_2 to the environment.

* The Minnesota environment contains large quantities of stored organic carbon. Two thirds of organic carbon is stored in soil, mineral wetlands, and peat. The 5.5 billion tons contained in these organic pools is equivalent to about 225 years of current CO_2 emissions from human activities (anthropogenic). Forests contain about three percent of total stored organic carbon, or roughly equal to 12 years of current anthropogenic CO_2 releases.

* Forests are a significant storage pool for carbon. As much as 10 percent of the CO_2 emissions are currently removed by increases in total forest biomass. Managed forest land will almost always fix more carbon than haphazardly treated forest land, but net increases in carbon storage also depend on rotation length and other factors.

* Individual trees and forests are, in general, net fixers and storers of atmospheric carbon for long periods.

* The manner in which peatlands, mineral wetlands and prairie soils are managed can have a major impact on CO_2 releases. The potential for releases of carbon to the atmosphere is particularly great for these land types.

* A planting program designed primarily to annually fix 10 percent of Minnesota CO_2 emissions is technically possible but will require a significant investment of land and money.

RECOMMENDATIONS

* The impact on the carbon balance should be considered in strategies and policies affecting wetlands and peatlands.

* The state should evaluate the merits of minimizing net losses of forested land, particularly where losses of forested land would increase summer temperature and, hence, use of air conditioning.

* The state is encouraged to continue the support of proper forest management and develop strategies for enhancing the stocking and productivity of forest lands. Examples include:

  1. improving the effectiveness of forest management.
  2. regenerating the backlog of understocked forest land on all ownerships.
  3. minimizing unnecessary losses to insects and diseases.

* Studies should be initiated to determine how different harvesting and land use regimes will affect the storage of carbon in forests.

* New plantings should be designed to obtain <u>both</u> carbon fixation and other benefits. The other benefits could include: 1) solid wood for products such as lumber and veneer which store carbon for long periods and provide for industrial development, 2) fuelwood which would substitute for fossil fuels, and 3) more favorable local climates which would be achieved by wind reduction, direct shading of buildings, and reduced heat island.

* Further evaluations are needed on the feasibility of using whole-tree burning technology as an alternative energy source.

A. Emissions Inventory

1. *Introduction*

Concern is growing over potential environmental changes that could be brought about by global warming. As a direct result of human activities, "greenhouse gases" are released to the atmosphere where, due to their long atmospheric lifetimes, they are accumulating in substantial quantities. At natural levels, many of these gases trap part of the sun's heat and warm the planet. However, rising levels of these gases can trap additional heat, causing an increase in the average temperature of the earth's surface, and altering the heat balance of the planet (Ramanathan 1988).

The "greenhouse gases" of most concern are carbon dioxide, methane, chloroflourocarbons (CFC-12, CFC-11), nitrous oxide, and tropospheric ozone (Ramanathan *et al.* 1987) (see Figure 3.1). Half of the "greenhouse effect" is contributed by CO_2 and is primarily the result of the burning of fossil fuels. Minnesota energy use is dominated by combustion activities involving fossil fuels (see Figure 3.2). In aggregate, fossil fuels account for roughly 80 percent of the total energy used in Minnesota.

Figure 3.1. Current contribution to global warming by gas

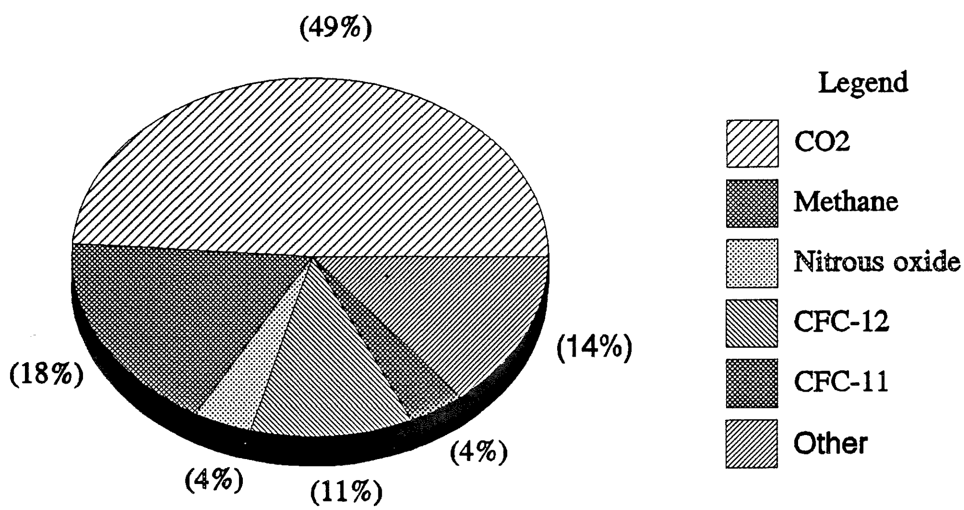
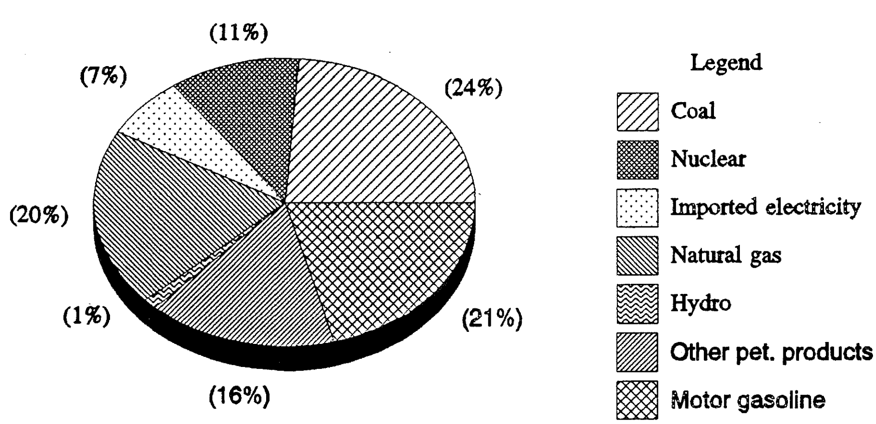


Figure 3.2. Primary energy use in Minnesota by fuel*



* As percent of an estimated 1988 consummption of 1247 trillion BTU's.

Source: MN Department of Public Service. 1990. Minnesota Energy Data Book. St. Paul, MN.

2. *Carbon Emissions from Fossil Fuel Combustion and Incineration*

Carbon dioxide is produced upon the combustion of any carbon-based fuel. Although fossil fuels are the principal form of fuel employed in Minnesota, other fuels that release CO_2 when burned include wood, ethanol, municipal solid waste, and refuse-derived fuel. Industrial and municipal sludge and hazardous waste are also incinerated in the state and release CO_2 to the atmosphere.

The rate at which CO_2 is produced during combustion for any carbon-based fuel depends on the carbon richness in the fuel, in particular, the ratio of hydrogen (H) to carbon (C). The higher the H:C ratio, the lower the amount of CO_2 released to the environment for each unit of energy produced from combustion. The hydrogen-to-carbon ratio is highest for natural gas, lowest for coal, with oil midway between the two. Thus, on a per energy unit basis, the combustion of coal releases the largest amount of CO_2 to the environment, and natural gas the least.

3. *Fuel Use and Incineration in Minnesota*

The statewide use of fossil fuels has varied considerably in recent years. Between 1986 and 1988 the variation was about 13 percent (MN Department of Public Service 1990). This was largely due to the changing relative contributions of coal and imported electricity to total Minnesota energy usage. Fossil fuel use in Minnesota in 1988, the most recent year for which data are available, is shown in Table 3.1. The total energy content of fossil and incinerated fuels in 1988 was about 1,100 trillion BTU. Coal use accounted for approximately 29 percent of the total, petroleum fuels about 43 percent, and natural gas and incinerated fuels the remainder (see Figure 3.3).

Figure 3.3. Fossil fuel use and incineration in Minnesota

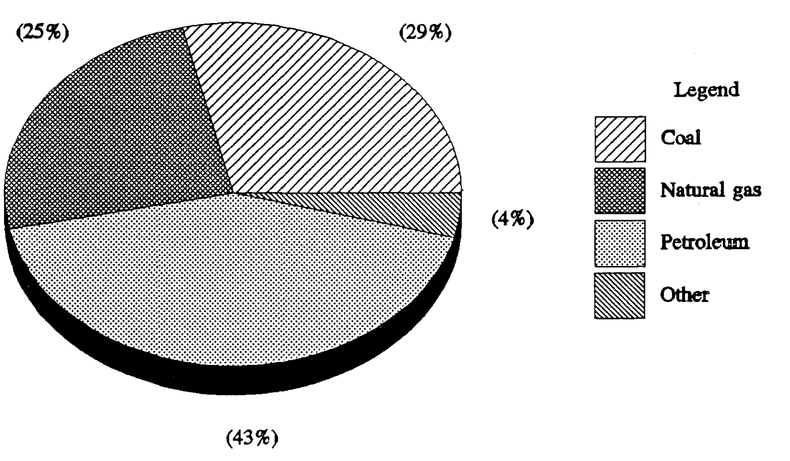


Table 3.1. Statewide 1988 fuel consumption in Minnesota by sector

Use Sector	Trillion BTU	% of Total
Transportation	355.4	32.3
Electrical/Steam	296.4	26.3
Residential	164.5	15.0
Industrial	138.7	12.6
Commercial	109.7	10.0
Agriculture	34.4	3.1
TOTAL	**1099.1**	

In Figure 3.4, electrical use is shown by major end-use energy sector. Using these percentages of electricity demand, it is possible to roughly approximate the distribution of secondary energy use in the state associated with carbon-based fuels. This is shown in Table 3.2. Transportation is the largest secondary use sector in Minnesota with agriculture being the lowest energy use sector.

Total statewide energy use, not excluding hydropower, nuclear power, and imports of electricity across state lines, amounted in 1988 to about 1,250 trillion BTUs, distributed among fuels approximately as shown in Figure 3.2. Total energy use, again not excluding noncarbon-based fuels, has remained relatively constant since 1972, varying between 1,100 and 1,250 trillion BTUs (MN Department of Public Service 1990).

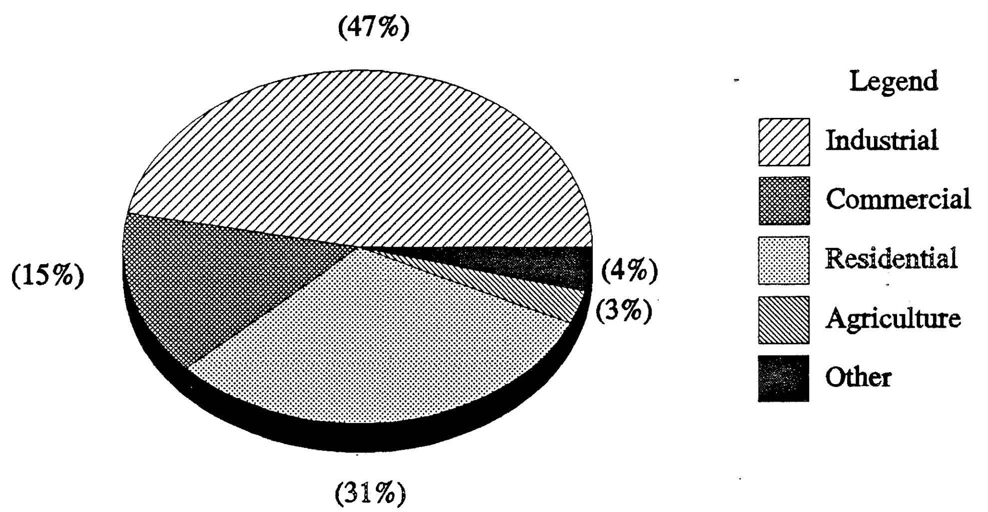
4. *Carbon Dioxide Emissions in Minnesota*

The total statewide releases of CO_2 to the atmosphere resulting from combustion activities are shown in Table 3.3. These releases are calculated based solely on in-state emissions. However, additional releases can be attributed to out-of-state emissions associated with the extraction, processing and transportation of fuels used in Minnesota (see Appendix A). Total in-state emissions for 1988 amounted to 24.4 million tons of carbon.

Table 3.2. Secondary energy use from carbon-based fuels by use sector

Secondary Use Sector	Trillion BTU	% of Total
Transportation	355.4	32.3
Industrial	289.8	26.3
Residential	256.1	23.3
Commercial	155.9	14.2
Agricultural	42.8	3.9
TOTAL	**1100.0**	

Figure 3.4. Electricity consumption by end use sector

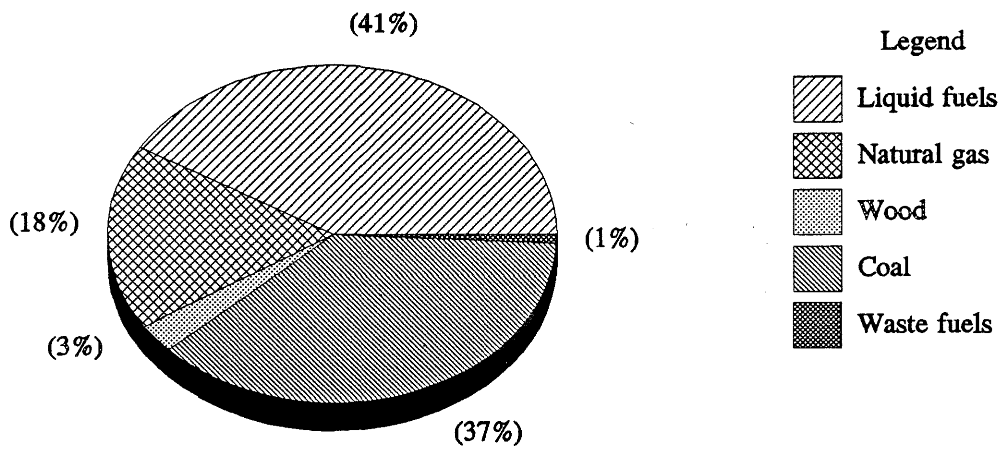


Source: PLC, Inc., "Conservation Potential in the State of Minnesota", report prepared for the Minnesota Department of Public Service, June 1988.

Table 3.3. Statewide emissions of carbon in CO_2 (1000 tons) for 1988 by fuel use sector and fuel

Fuel Type	Residential	Commercial	Industrial	Agricultural	Transportation	Electric/Steam	TOTAL
Natural Gas	1,833.7	1,258.2	1,056.7	0.0	92.7	83.1	4,324.4
Coal							
Bituminous	2.7	136.5	248.3	0.0	1.1	567.6	956.2
Subbituminous	0.0	0.0	391.5	0.0	0.0	7,384.5	7,776.0
Lignite	0.0	0.0	1.9	0.0	0.0	92.9	94.8
Coke	0.0	0.0	87.6	0.0	0.0	175.3	262.9
Total coal	2.7	136.5	729.3	0.0	1.1	8,220.3	9,089.9
Other Solid Fuels							
Wood	417.1	12.0	245.4	0.0	2.0	21.9	698.4
Solid waste	0.0	0.0	85.4	0.0	0.0	88.2	173.6
Liquid Fuels							
Distillate fuel oil No. 2	448.3	217.8	318.4	0.0	0.0	33.5	1,018.0
Residual fuel oil No. 6	0.0	45.9	151.4	0.0	0.0	0.7	1,980.0
Diesel fuel oil	0.0	0.0	0.0	407.0	1,248.3	0.0	1,655.3
Gasoline	0.0	0.0	0.0	198.7	5,511.9	0.0	5,710.6
Jet fuel	0.0	0.0	0.0	0.0	892.8	0.0	892.8
LPG	131.3	230.8	126.0	127.8	0.6	0.0	616.5
Ethanol	0.0	0.0	0.0	0.0	5.6	0.0	5.6
Total liquid fuels	579.6	494.5	595.8	733.5	7,659.3	34.2	10,096.9
Hazardous waste (MBTU)	0.0	0.0	0.01	0.0	0.0	0.0	0.01
Sludge (1000 short tons)	0.0	0.0	38.9	0.0	0.0	0.0	38.9
TOTAL	2,833.1	1,901.1	2,751.6	733.5	7,755.1	8,447.8	24,422.2

Figure 3.5. Minnesota CO2 emissions by fuel*



*As percent of an estimated emission of 24.4 million tons of carbon

In terms of CO_2, this is approximately 89.5 million tons of CO_2. Of this, coal combustion accounts for about 37 percent, liquid fuels (mostly petroleum) about 41 percent, and natural gas about 18 percent (see Figure 3.5).

As indicated earlier, estimated statewide CO_2 emissions have varied in recent years. This is due largely to the displacement of imported electricity generated in-state through the combustion of coal. In 1986 statewide combustion emissions are estimated to have been approximately 21.8 million tons, or roughly 15 percent lower than 1988 releases. These totals compare favorably with emissions estimates for Minnesota suggested by other sources. Renew America estimates a total statewide CO_2 emission from Minnesota for 1986 of 19.6 million tons of carbon which, if adjusted for differing assumptions about rates of release of carbon for each fuel, agree well with the estimates from the current study (Malchado and Pilz 1988).

Although not specifically evaluated in this report, it should be noted that a number of anthropogenic sources of CO_2 production and emission other than fuel combustion exist (Abrahamson 1989b, Deluci *et al.* 1987, Marland *et al.* 1989, Marland and Rotty, 1983) (see Table 3.4). Additionally, substantial amounts of electricity are imported into the state, amounting to 17 percent of all electricity consumed in Minnesota. In aggregate, these out-of-state or noncombustion releases of carbon could add on the order of 5 to 10 percent to the estimated statewide emissions of CO_2. This suggests an upper limit on statewide emissions of about 27 million tons of carbon in the form of CO_2.

Total combustion emissions of CO_2 nationally were estimated in 1986 at about 1,405 million tons of carbon (Malchado and Pilz 1988). Thus, Minnesota releases of CO_2 from combustion activities amount to about two percent of all CO_2 produced nationally through combustion, and less than half a percent of global emissions from combustion activities.

Table 3.4. Sources of CO_2 emissions not treated in this study

Peat harvesting and combustion
Cement manufacture
Use of SO_2 stack scrubbers
CO_2 from the atmospheric decay of methane[a]
Natural gas flaring during oil production
Imported edectricity produced out-of-state using a fossil fuel source
Decay of long-lived coal and oil-based solids and liquids (e.g., asphalt, benzene, xylene, toluene, creosote oil)

[a]Anthropogenic sources of methane in Minnesota include: natural gas pipelines, landfills, and livestock.

5. *Distribution of Statewide Emissions According to Primary and Secondary Energy Use Sectors*

The transportation and electrical generation/steam sectors each account for about one-third of CO_2 releases to the atmosphere in Minnesota (see Figure 3.6). The residential, industrial, and commercial sectors divide up about equally most of the remaining one-third. Agriculture is but a marginal emitting sector, accounting for approximately three percent of statewide emissions. For purposes of comparison, the distribution of 1986 emissions of CO_2 nationally according to primary energy use sector were estimated as: electrical utilities (33.4 percent); transportation (31.8 percent); residential (7.4 percent); and industrial/commercial (27.5 percent) (Marchado and Pilz 1988).

The electrical/steam generation sector includes both electrical utilities and utilities providing steam or heat for sale for residential, commercial, or industrial use. Examples of the latter type of utility include the Duluth Steam Cooperative or the Minneapolis Energy

Center. As noted above, the electrical/steam generation sector is not the final consumer of energy, but only a provider of finished energy products, principally electricity. Since the electricity generated in the electrical/steam generation sector is ultimately consumed in households, businesses and industries outside of the electrical/steam generation sector, the large amount of CO_2 produced during the generation of electricity can be apportioned among the various secondary or end-use energy sectors. This is done in approximate fashion using a percentage breakdown of electricity use between the residential, commercial, industrial, and agricultural sectors (see Figure 3.4). Secondary use sectors include the residential, commercial, industrial, agricultural, and transportation sectors. In Figure 3.7 is shown the distribution of estimated 1988 statewide CO_2 emissions by the secondary energy use sector. The transportation and industrial sectors each account for about 30 percent of CO_2 releases. The residential sector accounts for about 22 percent.

5a. *Fuel Use and CO_2 Emissions for the Transportation Sector*

Fuel use in the transportation sector is the largest energy consuming sector in Minnesota (see Table 3.1), but only the second largest CO_2 emitting primary use sector (see Table 3.3). All but a small fraction of the fuels used are petroleum based liquid fuels.

5b. *Fuel Use and CO_2 Emissions for the Industrial Sector*

The industrial fuel use sector is responsible for releasing about 2.8 million tons of carbon (10.1 million tons of CO_2) with the largest contribution coming from the burning of natural gas (39 percent) (see Table 3.3). As might be expected, fuel use in the industrial sector is dominated by natural resource extraction and refining industries (see Table 3.5).

Electrical use in the industrial sector constitutes 47 percent of total electrical usage in Minnesota (see Figure 3.4). The distribution of electrical use among the principal classes of industrial consumers of electricity is shown in Table 3.6. Again, the natural resource extraction industries are heavily represented. Since the electrical/steam generation sector accounts for about 35 percent of CO_2 releases statewide, and the industrial sector accounts for about half of electrical demand statewide, a relatively small number of industries account for a disproportionate large release of CO_2 to the atmosphere. Between metal mining, machinery manufacture, paper and allied products, food and kindred products, petroleum refining and pipelines, 20 to 25 percent of all statewide CO_2 releases to the atmosphere are accounted for.

5c. *Fuel Use and CO_2 Emissions for the Electrical/Steam Generation Sector*

Fuel use in the electrical/steam generation sector is the second largest energy consuming sector in Minnesota (see Table 3.1), but the largest CO_2 emitting primary use sector (see Table 3.3). The relatively high rate of CO_2 emissions from this sector is due largely to the disproportionate use of coal in the generation of electricity. The combustion of subbituminous coal, the principal type of coal in use in Minnesota, results in the release of about 70 to 80 percent more CO_2 per unit of energy produced than does the combustion of natural gas, and about 20 to 25 percent more CO_2 than does the combustion of refined petroleum products (see Appendix A).

Within this fuel use sector, Northern States Power Company (NSP) and Minnesota Power and Light (MP) are the two dominant fuel users within the electrical/steam generation sector. These companies supply roughly 90 percent of the energy from the electrical sector. In terms of CO_2 release, NSP and MP account for about 90 percent of all emissions from the electrical generation/steam sector (see Table 3.7) and in 1986 accounted for about 25 percent of all statewide CO_2 emissions.

5d. *Fuel Use and CO_2 Emissions for Other Sectors*

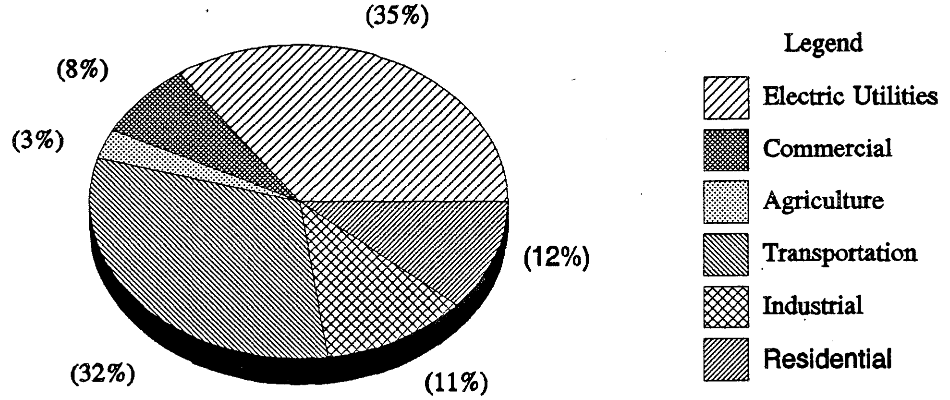
The major source of CO_2 emissions for the residential and commercial sectors is from the use of natural gas. About 65 percent of CO_2 releases for these sectors can be attributed to natural gas use (see Table 3.3). Liquid fuel use is also an important source of CO_2 from these sectors. Releases of CO_2 from the agricultural sector are attributed to the use of liquid fuels.

Table 3.5. Distribution of CO_2 emissions in the industrial fuel use sector for 1986

Standard Industrial Classification Category	% of Emissions
Paper and Allied Products	20
Petroleum Refining	19
Metal Mining	18
Food and Kindred Products	18
Education	6
Lumber and Wood Products	3
Other	16

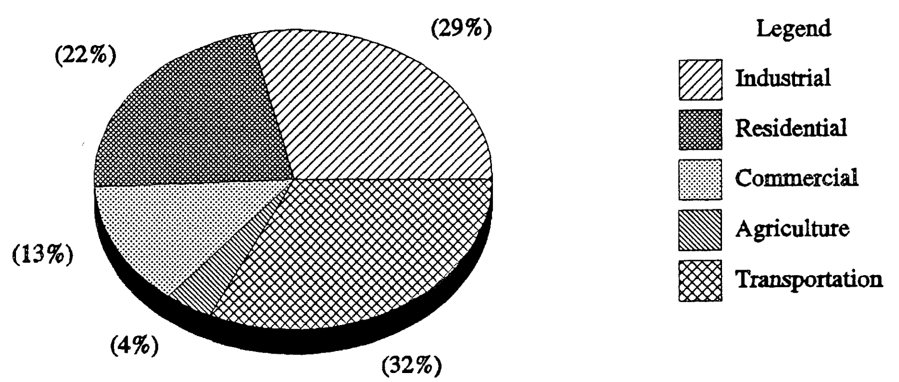
Source: Fuel use data, Appendix A.

Figure 3.6. Carbon dioxide emissions by primary fuel use sector*



*Based on a total estiamted emission of 24.4 million tons of carbon in 1988.

Figure 3.7. Carbon disxide emissions by secondary energy use sector*



*Based on a total estimateed emission of 24.4 million tons of carbon in 1988

Table 3.6. Electrical usage in the industrial fuel use sector for 1986

Standard Industrial Classification Category	% of Emissions
Machinery	30
Metal Mining	23
Paper and Allied Products	12
Food and Kindred Products	9
Pipelines	7
Petroleum Refining	2
Lumber and Wood Products	1
Other	16

Source: PLC, Inc., "Conservation Potential in the State of Minnesota", report prepared for the Minnesota Department of Public Service, June 1988.

Table 3.7. Statewide CO_2 emissions from the electric/steam sector by utility

Utility	Carbon (tons)	CO_2 (tons)
Northern States Power	3,648,934	13,380,641
Minnesota Power and Light	1,456,439	5,340,762
SMMPA	114,020	418,111
Ottertail Power	64,020	234,761
Virginia Public Utility	56,930	208,762
Interstate Power	57,677	211,502
Energy to Municipal Waste Incinerators[a]	56,094	205,697
Other	241,217	884,543
Total	**5,695,331**	**20,884,779**

[a] Other than NSP and UPA capacity. Values are for 1988.

Source: Minnesota Pollution Control Agency, Emissions Inventory System (1990)

B. Carbon Stored in Minnesota

An inventory was made of the carbon stored in the Minnesota landscape. By far, the largest storage pool of carbon in Minnesota is mineral carbonate in the sedimentary rocks (e.g. limestone) and in soils. However, the quantities of carbon stored in these components are not known, and mineral carbonates are relatively stable. The second largest storage pool is organic carbon which has been produced in Minnesota. More than half of this occurs in water saturated conditions, including peatlands, mineral wetlands, and lakes (see Table 3.8). The next largest amount of organic carbon, about two billion tons, occurs in the upper three feet of soils. Forest vegetation adds another 285 million tons. Crops and grasses were not considered because their shoots die each year and their roots are included in soil carbon. The amount stored in building structures, books, road surfaces, solid waste dumps and other semi-permanent products was not determined.

Average organic carbon storage in tons per acre within soils ranges from about 60 tons per acre in agricultural land on former prairie areas, to 28 tons per acre in deciduous forests, to 15 tons per acre on Canadian shield country such as the BWCA. Minnesota forests contain 1.6 percent of the U.S. total carbon in tree biomass, and store about 82 percent as much per acre as the U.S. average (Birdsey 1990). In contrast, Minnesota has about 25 percent of peatlands in the lower 48 states, a relatively large share. The total carbon stored in Minnesota peatlands is about 50 percent more than that found in Minnesota soils (see Table 3.8), whereas in the North Central Region as a whole, peatlands contain only about 17 percent the amount of carbon found in soils (Franzmeier *et al.* 1985).

Table 3.8. Organic carbon pools (billions of tons) of Minnesota

Pool	Carbon Storage	Percent of Total	Probable Range
Peatland	3.1	37	2.3-4.1
Lake sediments	2.6	31	0.8-6.2
Soil carbon	2.0	24	1.6-2.4
Wetland	0.4	5	0.2-0.5
Tree biomass	0.28	3	0.20-0.36
Total	8.4		5.1-13.6

Carbon stored in biomass varies with forest type (see Table 3.9). For the major forest types in Minnesota, maple-basswood contains the most carbon per acre. Due to the large total acreage in aspen, the aspen type contains about three times more total carbon held in biomass compared to any other single forest type.

Table 3.9 Carbon storage in forest biomass. Includes all above-ground biomass, plus coarse roots.

Forest Type	Average Carbon Storage (tons/acre)	Carbon Storage in MN (millions of tons)
Jack Pine	6.5	13.8
Red Pine	5.6	18.1
White Pine	1.6	24.2
Balsam Fir	14.0	17.5
White Spruce	1.5	12.5
Black Spruce	12.0	11.5
White Cedar	8.5	17.2
Tamarack	5.0	10.6
Oak-Hickory	20.3	23.2
Elm-Ash-	14.3	20.1
Cottonwood	33.3	26.1
Maple-Basswood	91.5	17.2
Aspen	23.7	24.6
Paper Birch	9.3	16.9
Balsam Poplar	0.2	1.7
Nonstocked*	28.3	24.0
Reserved		
Subtotal	275.7	20.2
Woodland**	10.0	
Total	285.7	

* Commercial forest land with tree stocking less than 16.7%.

** Forest land incapable of producing 20 cubic feet per acre of annual growth, or of yielding crops of industrial wood under natural conditions because of adverse site conditions.

Minnesota forests contain about 276 million tons of carbon (see Table 3.9). An additional 10 million tons is contained in woodland. At least since 1977, each year about 2 to 4.5 million tons of carbon have been added to existing forest lands. This estimate is based on preliminary evaluation of Forest Inventory and Analysis data. This 2 to 4.5 million tons represents about 10 percent of the annual emissions of carbon. It is likely that most of the gain is derived from the continuing transformation of understocked forest stands into more fully stocked stands and to the lack of harvest in certain well-stocked older forest stands. Much of Minnesota's forest land is still understocked and standing biomass should continue to increase for a number of years. In the long term, it may be possible to increase the amount of carbon stored in the forest by 25 percent (Ed Sucoff, University of Minnesota, personal communication). Increases of 25 percent would be equivalent to fixing three years of annual emissions of CO_2 (see Table 3.3).

The improvement in stocking in forest stands can be attributed to two principal factors: 1) recovery of forest land from past uses, and 2) current, more scientific management practices. Many of the understocked stands in Minnesota are a reflection of the past practice of high-grading. The best stems were removed, and remaining vegetation was degraded, sometimes to shrub fields. Poor stocking may also be related to the slow recovery from past fires and the slow restocking of the many acres of abandoned agricultural land.

Current management practices achieve full stocking much earlier than in the past after harvest or conversion from agriculture. Planting immediately after logging, pest control, site amelioration, and control of shrubs are among the practices that enhance regeneration.

Soil carbon accumulation and storage depend on climate, vegetation, and management practices. On forest soils timber harvest may have little effect on soil carbon (Boone *et al.* 1988, Harmon *et al.* 1990, Alban 1990, personal communication). In contrast management can have an effect on prairie soils. Prairie soils contain two to three times more carbon than forest soils (Franzmeier *et al.* 1985). The amount of carbon in prairie soils can and often has been lowered by 40 to 50 percent as a result of repeated cultivation for agricultural crops. Were this land returned to prairie conditions, large amounts of carbon could be returned to the soil, but little carbon would be stored in living biomass. If these former prairies were afforested, losses in soil carbon would probably continue but carbon in living biomass would increase. Unfortunately, the rates of these potential gains and losses in soil carbon are not known. What can be stated is that the carbon fixed in the trees planted on former prairie soils would be somewhat offset by an actual loss of soil carbon as well as the forgoing of the soil carbon which would have accumulated had prairie been reestablished.

Peat accumulates slowly. Once formed, peat may be stored for thousands of years. If peatlands are drained or mined, the peat is exposed to oxygen and relatively high temperatures. Under these conditions of exposure, the organic material decomposes and the carbon stored within the peat returns to the atmosphere as CO_2, resulting in a reduction in stored carbon. A similar release of carbon occurs when mineral soil wetlands or shallow lakes are drained. There are 114 tons of carbon per acre in the average mineral wetland and 516 tons per acre in the average peat bog. More carbon is stored per acre for mineral wetlands and peatlands than in forest biomass. On an acre basis, mineral wetlands contain four times more and peatlands contain 20 times more organic carbon than is found in forest biomass.

A policy of "no net loss of wetlands", which includes provisions for creating a wetland for one which has been drained, will not maintain the carbon balance. This policy will likely result in a rapid loss of the carbon it took centuries and thousands of years to store. The new wetland will take many many years to store an equivalent amount of carbon. The net effect will be to increase CO_2 releases to the atmosphere. An increase in net acreage of wetlands and peat bogs would slowly but continuously increase carbon fixation. Currently, active drainage and mining of peat for use as fuel or as organic amendments is not extensive in Minnesota (Erwin Berglund, DNR/Minerals Division, personal communication).

C. Carbon Fixation by Shade Trees, Shrubs, and Forest Land in Minnesota

Trees provide multiple benefits to society and the environment. In recent years, trees and shrubs have been offered as part of the solution to counteracting the rise in level of CO_2 in the atmosphere. Trees and shrubs reduce CO_2 levels in the atmosphere in two ways. One way is directly through fixation or the incorporation of carbon into biomass. Interest has increased in the planting of trees and shrubs in rural and urban settings to directly fix or sequester atmospheric carbon and, thereby reduce the buildup of CO_2 in the atmosphere. The second way to reduce CO_2 releases to the atmosphere is indirectly by reducing demand for fossil fuels. Trees reduce energy use when they act as windbreaks, provide shade for homes and other buildings, and reduce the summer temperatures of city heat islands.

1. *Carbon Fixation by Shade Trees and Shrubs*

Cumulative carbon fixation was estimated for a number of shade trees and shrubs (see Table 3.10). For five typical deciduous species (sugar and Norway maple, hackberry,

Table 3.10 Cumulative tons of carbon fixed per open-grown tree by age for eight species common in the Twin Cities. SM=sugar maple, NM=norway maple, GA=green ash, HB=hackberry, LIN=linden, SRP=siouxland/robusta poplar, BS=blue spruce, WS=white spruce.

Age	Species							
	SM	NM	GA	HB	LIN	SRP	BS	WS
5	0.03	0.03	0.03	0.00	0.01	0.01	0.00	0.01
10	0.03	0.03	0.04	0.01	0.02	0.12	0.01	0.01
20	0.10	0.09	0.16	0.09	0.10	0.42	0.05	0.02
30	0.30	0.29	0.31	0.27	0.26	0.63	0.15	0.08
40	0.57	0.79	0.45	0.57	0.46	0.77	0.28	-

linden, and green ash), carbon fixation at age 30 ranged from 0.26 to 0.31 tons. The spruces fixed less carbon. By age 40, the open-grown hardwood species have fixed between one-half and three quarters ton of carbon per tree. Shrubs fix minor amounts of carbon, since they have many small stems with little wood (see Table 3.11). The large shrubs, lilac and arborvitae, fix larger amounts of carbon for a longer time.

2. *Carbon Fixation in Forest Stands*

Forests managed intensively for timber production sequester carbon faster than "average" forests of Minnesota (comparison of Table 3.12 with 3.13, Table 3.14 with 3.15, and Table 3.16 with 3.17). Over a period of 50 years in Minnesota forests, traditional plantations can fix 25 to 60 tons of carbon per acre depending on site quality and species. Rotation length, species selection, stocking control, and pest control are important factors which will influence the total amount of carbon fixed in forest biomass.

Table 3.11 Cumulative pounds of carbon fixed per shrub by age for four species common in the Twin Cities. WC=pyramidal white cedar, HC=highbush cranberry, ROD=red-osier dogwood.

Age	Species			
	WC	Lilac	HC	ROD
5	3	2	3	3
10	17	11	20	20
15	46	34	63	63
20	93	75	-	-
25	160	138	-	-

Reductions in atmospheric CO_2 could be achieved while managing existing forest lands for wood, wildlife, recreation and other goods and services. As mentioned in Section III.B., the potential exists for significantly increasing the amount of carbon stored in forest biomass. Increasing carbon storage on existing forest land by an average of about 0.1 percent per year could reduce anthropogenic CO_2 levels by one percent per year.

3. *Carbon Fixation in New Forest Plantations*

Forest plantations, including short rotation hybrid poplar, can incorporate (fix) from 25 to 105 tons per acre of carbon over a 60 year period. The amount varies with species, site quality, and tree cutting regimes. The next paragraph indicates the number of acres and the costs of establishing plantations which would fix 10 percent of all the carbon emitted over a 60 year period, assuming 1988 emission levels throughout, i.e. 10 percent of 1.5 billion tons (24.4 million tons per year for 60 years). If harvested wood is burned or used for paper, most of the carbon harvested is returned to the atmosphere as CO_2. However, burned wood presumably substitutes for fossil fuels. If used for lumber, the storage of carbon by material already harvested may be prolonged considerably.

In the strategy designed to fix carbon as soon as possible, all of the trees would be planted the first year. For red pine and oak, respectively, this would mean that 2.3 or 3.0 million acres would have to be planted in, say, 1995 so that 150 million tons of carbon would be fixed by 2045. The acreage is about 7 to 9 percent of the nonforest land in Minnesota. After 2045, the forest could move to sustained yield by harvesting and replanting 48 or 60 thousand acres per year. If carbon were the only product, and there were no management costs after establishment, the cost per ton of carbon at age 60 would be from $2 to $10 when land rental costs are not considered, and from $22 to $70 when land rental costs are considered (see Table 3.18). As another strategy, instead of planting the entire area immediately, a portion of the total acreage could be planted each year for the next 20 years. This would spread out planting, but because of the delays getting started, a larger total area of new forest would be required. A large planting program may be feasible. The Conservation Reserve Program has retired over one million cropland acres to grass and trees during a five year period.

In a third strategy, 1.5 million acres of hybrid poplar would be planted immediately, and the forest would be harvested three times during the 60 year period (see Table 3.19). Hybrid poplar is fast growing but very short lived and has been considered a potential fuel for electricity generation.

Table 3.12. Cumulative carbon fixed (tons/acre) by mixed-species oak forests. Based on USFS FIA Empirical Yield Tables (Hahn and Raile 1982). Data are smoothed over time as described by Walters et al. (1991).

	Site Index		
Age	40	60	80
10	10	12	15
20	13	17	22
30	16	21	27
40	18	25	32
50	20	28	36
60	22	31	40
70	24	34	44
80	26	37	47
90	28	39	50
100	30	41	53

Table 3.13. Cumulative carbon fixed (tons/acre) by natural well managed mixed-species oak forests. Based on Gevorkiantz and Scholz (1948).

	Site Quality			
Age	poor	fair	good	vgood
20	10	14	16	18
40	22	28	33	38
60	31	41	49	58
80	41	53	63	74
100	49	62	75	88
120	55	70	85	99

Table 3.14. Cumulative carbon fixed (tons/acre) by mixed-species white spruce forests in northern Minnesota. Based on USFS FIA Empirical Yield Tables (Hahn and Raile 1982). Data are smoothed by methods of Walters et al. (1991).

	Site Index		
Age	40	60	80
10	5	6	6
20	7	8	10
30	10	11	12
40	12	13	15
50	14	15	17
60	15	17	18
70	16	18	19
80	18	19	20
90	18	20	21
100	19	21	22

Table 3.15. Cumulative carbon fixed (tons/acre) by unmanaged white spruce plantations in central Ontario. Based on yield tables by Stiell and Berry (1973). Data from stands with 7 x 7 foot initial spacing and no thinning.

	Site Index			
Age	50	60	70	80
20	1	4	7	10
30	10	16	22	28
40	20	28	36	44
50	26	36	46	55

Table 3.16. Cumulative carbon fixed (tons/acre) by mixed-species red pine forest in Minnesota. Based on USFS FIA Empirical Yield Tables (Hahn and Raile 1982). Data are smoothed by methods of Walters et al. (1991).

	Site Index		
Age	40	60	80
10	11	11	10
20	12	14	16
30	13	18	23
40	15	22	29
50	17	26	35
60	19	30	41
70	21	33	46
80	23	37	51
90	24	40	55
100	26	43	59

Table 3.17. Cumulative carbon fixed (tons/acre) by intensively managed red pine plantations in Minnesota. Based on initial stocking of 800 trees per acre and no thinning. After Lundgren (1981).

	Site Index			
Age	50	60	70	80
20	2	4	7	11
30	8	14	21	31
40	17	27	39	53
50	27	41	54	67
60	36	49	63	78
70	40	54	69	85
80	42	57	73	90
90	44	60	77	94
100	45	61	79	97

Table 3.18 **Costs and area requirements to fix one ton of carbon in 60 years using red pine plantations (S.I.* = 60) or well managed (good site) oak forests.**

Red Pine	With land rental	No	No	Yes	Yes
	Discount rate (%)	0	10	0	10
	Implied cost of C ($/ton)	2	10	22	40
	Acreage required	.016	.016	.016	.016
Oak	With land rental	No	No	Yes	Yes
	Discount rate (%)	0	10	0	10
	Implied cost of C ($/ton)	2	8	62	70
	Acreage required	.02	.02	.02	.02

Costs calculated from Tables 4.6 and 4.7, and acreage in Tables 3.13 and 3.17.

* S.I. Site index is a measure of site quality based on the height of the dominant trees in a stand at an arbitrarily chosen age.

Table 3.19. Yield table of carbon fixed (tons/acre) by hybrid poplar in the southern half of Minnesota. Data are based on *Populus tristis* (Ek and Dawson), several hybrids planted around the upper midwest in 1986 (Hansen 1990) and personal communication with Edward Hansen.

	Site Quality	
Age	Poor	Good
1	0	0
2	0	0
3	0	0
4	0	1
5	1	2
6	2	4
7	3	6
8	4	9
9	6	12
10	8	15
11	10	19
12	12	23
13	14	27
14	16	31
15	18	35

IV. TREE PLANTING FOR ENERGY CONSERVATION

CONCLUSIONS

* Trees located east and west of a building are most effective in reducing total energy demand.

* Base heating and cooling costs are lower in east-west oriented buildings than in north-south oriented buildings.

* The annual change in utility costs due to tree planting for energy conservation reflects the impact of the tree on both cooling and heating energy demand. Reductions in annual cost of cooling combined with heating depends upon where the home is located in the state and where the trees are located in relation to the building. Greater savings are possible in the southern half of the state compared to the northern part of the state.

* Strategic tree planting can substantially reduce air conditioning energy demand while minimizing the reduction in winter solar gain (i.e. heating). Tree planting which shades windows of buildings can reduce air conditioning demand by up to 32 percent.

* In the southern half of the state, direct shading from trees placed west and east of houses yield annual energy savings of 1 to 2 percent.

* Benefits from tree shading likely represent only 10 to 30 percent of the total energy benefit expected from trees. Other important benefits will include reductions in wind and reductions in summer temperatures of urban heat islands.

* The effects of tree shading on utility costs and energy conservation are distinctly different between the northern parts of the state and the southern half of the state. When only shading effects are considered, no utility savings are likely for houses located in the northern portion of the state. For the central and southern part of the state annual utility costs will be reduced for all landscapes, orientations and insulation levels studied.

* Tree planting for energy conservation is a good investment in the southern half of Minnesota depending on tree costs, number of trees planted and the individuals desired alternate rate of return on investment. Smaller trees ($40) pay for themselves in most situations. Larger, more expensive trees ($120) only pay for themselves when the alternate rate of return is very low or when other benefits of larger trees are considered.

* Tree planting reduced the amount of CO_2 released to the atmosphere for all

locations, building orientations and planting schemes. Reductions in total emissions over 40 years ranged from 1/10 ton to 3 tons per house.

* Currently in Minnesota, there are 3.6 million trees providing an average tree cover of 30 percent.

RECOMMENDATIONS

* The state should develop educational materials and an outreach program to inform the public, local decision makers, and forestry and landscape professionals about strategic energy conservation planting programs.

* The state should set a goal of achieving 50 percent or more tree cover throughout communities in Minnesota.

* The state should establish a $13.5 million annual urban and rural tree planting program. Of the total, $8 million should be targeted to the urban areas and $5.5 million for the rural areas. The cost of the program should be borne by the primary fuel use sectors based on the percentage of CO_2 emissions contributed by each of these sectors.

* For the rural areas, the tree planting program should be coordinated with existing federal and state programs by piggy-backing new funds with existing cost-share programs.

* Within neighborhoods, efforts should be made to ensure that plantings on adjoining private and public properties are coordinated to maximize mutual benefits.

* The state should fund research to quantify the wind shielding and summer air temperature benefits of tree planting under Minnesota community conditions.

* The state should support establishment of a "MINNESOTA RELEAF" program to promote tree planting throughout the State. "MINNESOTA RELEAF" would be patterned after the "Global Releaf" program which is a national education, action and policy campaign of the American Forestry Association. "MINNESOTA RELEAF" would be an organizing vehicle for communities and volunteer action in tree planting and tree care programs. "MINNESOTA RELEAF" would also actively solicit donations from businesses, foundations, and private citizens to assist in these efforts. It would help insure that local contributions be used to support local tree efforts.

* Guidelines for community involvement, technical assistance and cost-share programs need to be developed at the state level to coordinate tree planting

and tree care programs.

* The state has two designated committees that are currently providing guidance on two federal programs encompassing a major tree planting initiative. These committees are the Stewardship Committee (rural) and the Minnesota Shade Tree Advisory Committee (urban). These committees should be requested to provide assistance in initiating and implementing the new program.

* Guidelines, policies, and incentives programs should be developed by the state to reduce the number of trees removed or damaged during construction in urban areas.

* The legislature should fund the LCMR proposal on energy conservation to address data gaps on wind effects and temperature change.

A. Project Methodology

This research focused on the impacts of tree shade on home heating/cooling energy use patterns of prototype single family residential structures under a range of Minnesota climatic conditions. Only the literature search (and, to a limited extent, the preliminary planting guidelines) addressed other energy related benefits from plants. The current simulations and cost benefit analysis do not include important probable energy savings due to reductions in winter wind infiltration, modification of outdoor air temperature (changes in "heat island", impacts of reduced areas of paving or increased vegetation and evapotranspiration), nor important issues of human comfort and environmental quality. This focus on tree shade, the most straight forward direct effect of vegetation, may be viewed as an initial step towards defining the role of vegetation in energy conservation.

In addition, because of the large data set needed to accurately calculate energy use for any one building-planting scheme, the quantification is limited to one prototype tree and one prototype building with two insulation levels and two orientations at three latitudes. Furthermore, the cost benefit analysis only quantifies benefits from tree shade on building windows.

1. *Methodology for Tree Shade Simulations and Energy Use Computations*

The purpose of this part of the project was to determine how much shade is cast on a prototype single family home by specific locations of trees and to determine how that shade effects energy loads needed to heat and cool that home.

This study was intended to examine the energy conserving potential of trees on locations representative of a range of climatic conditions across Minnesota. Three locations (with national weather service station data tapes) were selected to represent Minnesota climatic conditions: the Twin Cities, International Falls, and Sioux Falls, SD (the later is the weather data available best representing southwestern Minnesota). Weather data tapes of each city were used in conjunction with the CALPAS3 program. Shading and insolation patterns were based on simulations done for three latitude/locations: the northern state boundary - International Falls (49 degrees north), the Twin Cities (45 degrees north), and the southern state boundary - Sioux Falls (43.5 degrees north) (see Figure 4.1).

A prototype one-story ranch house with basement comparable to buildings used in other energy use studies was developed for simulation purposes. The test building was assumed to be sufficiently insulated that the primary impact of direct shade from vegetation is through the windows. That is, no prediction was made of any effects vegetation may have on the building's roof, and consideration of impacts on walls was limited. The building was configured to be evaluated at both east-west and north-south orientations. This was intended to reflect differences in building orientation found in real situations and to allow comparison of solar gain and shading differences due to orientation.

A single prototype test tree species, the green ash, was selected because it possesses the following characteristics. The green ash grows well in all regions of the state, is moderately fast-growing, has a relatively advantageous period of foliage (moderately late to set on leaves in spring and moderately early to lose leaves in fall), and has a fairly typical transmissivity of light through its leaves and branches (neither very dense nor open). This is not intended as an endorsement of ash which are already overplanted in the state. To evaluate the effectiveness of a tree from planting through maturity, a series of representative tree sizes were selected for the shading simulations (see below).

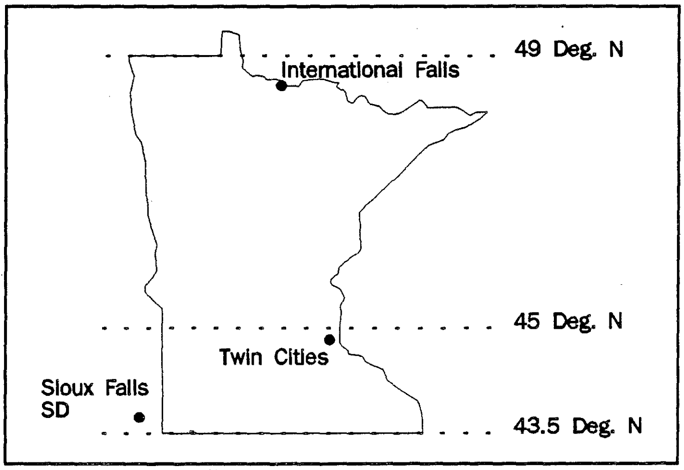


Figure 4.1. Cities and latitudes selected to represent Minnesota climatic conditions

To assess reasonably optimal tree shading patterns on windows, tree locations were sought which both maximize solar access during the heating season and maximize shade during the cooling season. For each building orientation, a set pattern of two or four prototype trees per site were tested. For the east-west oriented building, four trees (one each to the west, southwest, southeast, and east) were tested. For the north-south oriented building, the shading effects of two trees placed west of the building in the shading computer simulations were extrapolated to represent three scenarios: two trees to the west, two trees to the east, or the combined four trees (see Figure 4.2).

The primary plant characteristics influencing shading patterns are the transmissivity

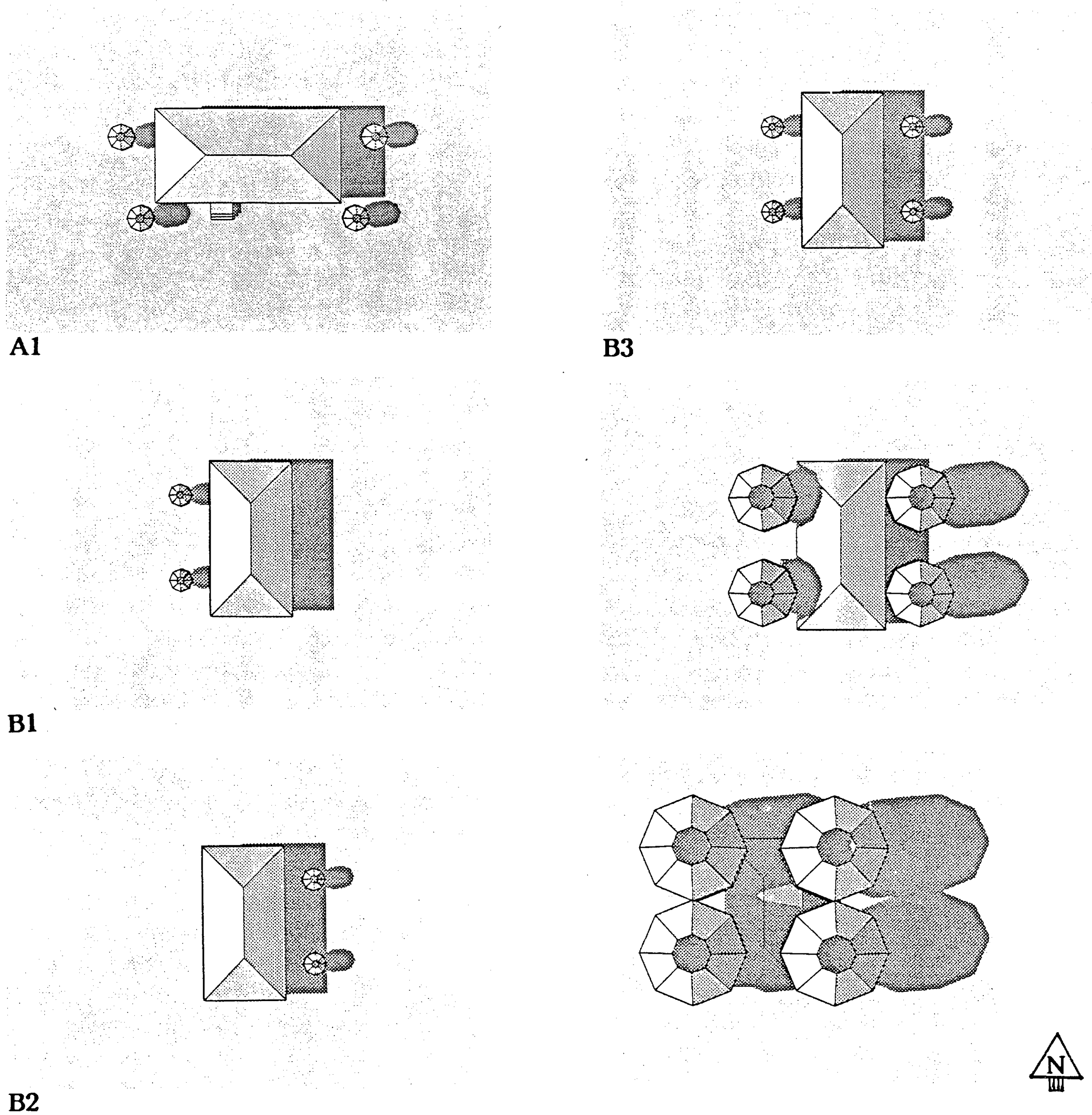


Figure 4.2. Test tree locations
Tree shade and home energy use were tested for two building orientations: east-west - the "A" tree-building configuration, and north-south - the "B" building configuration. Four trees were used for the "A1" configuration with their placement indicated above. For the north-south oriented building, either two trees were placed to the west as in "B1", two trees were placed to the east as in "B2", or these were combined as four trees as in "B3". Here they are shown as 10 foot tall trees and B3 is also shown with the same trees at 25 foot (left center) and 40 foot tall (left bottom). The shadows are typical of those that would occur 3:00 pm CDT in July in the Twin Cities.

and foliation period of the prototype tree. For this study, the typical foliation period of green ash was based on University of Minnesota Landscape Arboretum observations on green ash (Pellet 1990), and information from several other sources. The foliage and branch transmissivity was based upon adapted measurements taken of ash in Pennsylvania (Heisler 1990b).

The variables tested in the shading simulations were:

* *three latitudes (43.5, 45, 49 degrees north)*
* *one building (24'x 56' with 192 square feet of windows, 1 foot roof overhang)*
* *two building orientations (east-west and north-south)*
* *three basic tree heights (10', 25', and 40')*
* *one arrangement of trees per orientation*

SALADDS (with DDDIBM5) and CALPAS3 were the computer programs used for the shading and energy use simulations, respectively. Shading data generated for the 21st of each month from December through July provided a sample for each month of the year. CALPAS3 integrated the tree shade data with weather and building energy use information to quantify the impacts of tree shade on energy loads and costs. A unique solar gain factor for every window was computed based upon orientation, tree and building overhang shade, and tree transmissivity and foliation period. Then CALPAS3 runs were done to yield data on the cooling and heating energy loads for each latitude-building-tree combination. Using assumed heating and cooling efficiencies and gas and electricity costs, total heating and cooling costs and the subsequent increase or decrease in CO_2 emissions were determined. This data was used by project economists for the cost benefit analysis.

2. *Financial Analysis Procedures and Assumptions*

Planting trees around a house to reduce utility costs can be viewed as a kind of financial investment. Initially, a certain amount of money is placed in the investment "account" when the trees are purchased and planted. Then, over time, the investment pays "dividends" in the form of reduced utility bills. If a homeowner views the tree planting project strictly as an investment -- that is, if he or she is only concerned about monetary impacts -- then the project will have to earn some minimum rate of return or the homeowner will invest his or her money in something else. This is the perspective that was taken in the analysis that follows. However, since the impacts of tree planting projects on carbon emissions were also an important aspect of this study, it was necessary to find a way to include these effects in the analysis in addition to the purely financial impacts of tree planting.

It is important to acknowledge the narrowness of the analysis presented in this section. Only a few of the ways that a homeowner might benefit from planting trees in his or her yard have been quantified and thus included in the analysis. The only cost that has been considered is the initial investment in the trees. Even the cost of actually planting the trees has been ignored under the assumption that the homeowner will plant the trees or that the trees will be planted with volunteer labor. Under this assumption, the cost of the smaller trees was assumed to be $40.00 per tree and the cost of the large trees was assumed to be $120.00. Other expenses that have not been included are those associated with watering, pruning, and ultimately disposing of the trees. However, there also are many benefits that have been ignored, including possible increases in home values, aesthetic benefits, and utility savings that were not quantified in this study (such as wind effects and heat island effects). While it would be desirable to include all relevant factors, this was not possible within the constraints of this study. Nevertheless, research elsewhere indicates that the benefits that have been ignored are larger than the expenses that have been ignored. Thus, the omissions should be regarded as being conservative.

In order to compare carbon effects with financial effects, it is necessary to find a common yardstick with which to measure both effects. This means assigning a value to reducing the amount of carbon in the atmosphere. Since no one knows what this value should be, the next best solution is to determine what it costs to reduce the amount of carbon in the atmosphere by a given quantity in each situation. Then, as long as it can be agreed that the value of reducing the carbon in the atmosphere is greater than this cost, the tree planting project is justifiable in that situation. In each case, therefore, the tree-planting project was evaluated two ways: 1) looking only at the financial aspects, the project was evaluated as an investment, and 2) given the performance of the project as a financial investment, a cost-price for reducing atmospheric carbon by means of that project was calculated. In some cases, tree planting performed well solely on the basis of the financial factors. In those cases, carbon effects can be viewed as extra (free) benefits, and cost-prices were negative.

Many criteria have been developed for evaluating the performance of investments. The criterion used here is the net present value. The net present value (NPV) is obtained by discounting each cost and benefit resulting from a project back to the present using some prespecified alternate rate of return[1] and summing the results. When the NPV of a project is positive, it is a good investment relative to other investments yielding the alternate rate of return.

The difficult part of applying the NPV criterion is determining the appropriate alternate rate of return (or discount rate). Different individuals will have different alternate rates of return depending on their investment options, their attitudes towards risk, and whether they are net borrowers or lenders. Rather than assume that any one rate is the correct one, three discount rates were used in this analysis. The three rates of return used

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[1] To discount to the present a value to be obtained at some later date requires finding the amount that would have to be invested now in an investment yielding the given alternate rate of return in order to yield the given future value at the given future date. For example, to obtain $100.00 five years from now, it would be necessary to invest $71.30 now in an account yielding 7 percent simple interest per year. Thus, $71.30 is the *present value* of $100.00 five years from now, given a 7% discount rate.

here are 0 percent, 4 percent, and 10 percent. These are real rates of return, which means that they are rates that might be earned over and above inflation. Assuming a four percent inflation rate, these rates would correspond to nominal rates of return of 4 percent, 8 percent, and 14 percent, respectively. These discount rates are commonly used in evaluating the large spectrum of financial options available to the consumer. The lowest rate corresponds to a slightly better rate than that commonly earned on longterm government bonds, the middle rate corresponds to a rate slightly lower than the historic rate of return on U.S. stocks, and the higher rate is about equal to typical interest rates on relatively low cost consumer loans. The zero real rate of return is also included because it corresponds to the case of no discounting. However, some studies suggest that consumers expect a much higher rate of return on investment with respect to energy conservation activities than with other, more conventional, financial options.

Tree planting in rural areas provides an additional opportunity for sequestering carbon. One question to consider is what is the cost to reduce CO_2 in the atmosphere by such plantings. This part of the analysis considers the cost-effectiveness of reducing atmospheric carbon by increasing the area of forest in Minnesota. The result of the analysis is a cost-price for carbon sequestration for each forest covertype considered. These cost-prices give the value that would implicitly be assigned to the reduction of one pound of atmospheric carbon if the acreage of each forest type were increased purely for the sake of sequestering carbon. Thus, the present values of the costs for establishing each type of forest are compared with the present values of the carbon sequestered for each forest type and interest rate. The value for carbon sequestration that makes this net present value equal to zero is found. This is the price at which the benefits from carbon sequestration exactly balance with the costs of establishing the forest.

Six forest types are considered. They are: 1) mixed-species oak forest in southern Minnesota, 2) well managed mixed-species oak forest in southern Minnesota, 3) mixed-species white spruce forest in northern Minnesota, 4) intensively managed white spruce plantations (in Ontario, but similar to northern Minnesota), 5) mixed-species red pine forest in Minnesota, and 6) intensively managed red pine plantations in Minnesota.

Two types of costs are considered: the cost of regenerating the stand, and the land rental for holding the land out of other productive uses. Since in some cases (highway right-of-way, for example), the land has no alternative use, the cost-price is calculated with and without the land rental cost. Regeneration costs are assumed to be $130.00 per acre for all forest types.[2] The land rental rates are based on cash rental rates for low quality agricultural land in Minnesota.[3] Rental rates for oak types are based on an average rental rate for the six most southern sub-state regions, and rental rates for red pine and white

[2]This value was provided by Bob Pajala, Division of Forestry state silviculturist.

[3]Smith, M., M. Kilgore, and K. Thomas. 1990. Minnesota's farm cash rental market: 1989 -- with estiamtes for 1990. (FM665). St. Paul, MN; Univ. of Minnesota, Minnesota Extension Service, 6 pp.

spruce are based on the average rental rate for the four most northern sub-state regions. Management costs other than regeneration are not considered.

The analysis was performed for two time horizons: 40 and 60 years. The 40-year time horizon was used to be comparable to the 40 year time horizon of the urban study. The longer horizon is more compatible with typical rotations for forest stands. No consideration was given to what should be done with the stand at the end of the time horizon.

3. *Methodology for Development of Planting Design Guidelines*

The purpose of this part of the project was to describe more broadly the potential for using landscape plantings to conserve energy and to illustrate some representative examples of placement of plants for energy conservation on Minnesota sites.

Based upon the test results and the evaluation of other energy conservation functions of plants, preliminary energy conservation planting design guidelines were developed for Minnesota. Only the prototype house used for shading simulations was utilized to illustrate basic planting for energy conservation guidelines. Emphasis was made on illustrating the building-site combinations used in the project shading and cost benefit analyses. These were contrasted with illustrations showing locations of plants which result in shade in the wrong location or season. The combined locations of trees to maximize desirable shade and to buffer prevailing winter winds (without negatively impacting building shading solar gain conditions) were illustrated at a typical suburban neighborhood scale. These locations were based upon interpretation of shading simulation results and conclusions drawn from publications, but can not be directly linked to the quantitative data produced in this study.

B. Results of Energy Use Simulations and Cost Benefits Analysis

1. *Shading Simulation Results*

The effects of tree shade on the test buildings were compiled for each hour and each month of the year. Illustrative examples of the types of shadow patterns created by test trees during various seasons and months were determined (see Figures 4.3 to 4.5). These indicate differences in shadow patterns between trees of different sizes for the two building orientations at representative times of year. Analysis of the shading patterns indicated that the tree placements tested provided good solar access at midwinter and good shadowing of the west and/or east facades when trees were placed nearby.

The most difficult times of year to achieve favorable shading patterns were in the transitional months. In Minnesota, considerable heating fuel is still needed in February, March and April and beneficial solar gain is quite high on the west facades in mid-afternoon. Unfortunately, trees placed east and west of the building for optimum shade in July and August, also shade significantly in late winter. The implications of this situation on energy consumption are further discussed below.

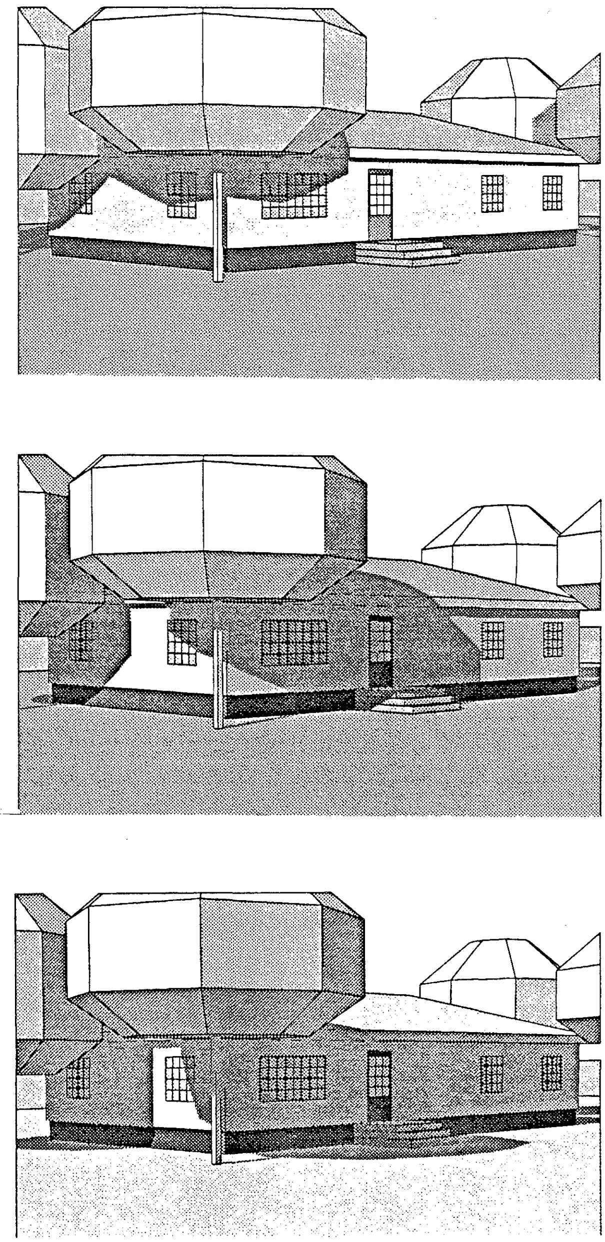


Figure 4.3. Shadow patterns from twenty-five foot tall trees on an east-west home
Four trees next to a east-west oriented home (at the Twin Cities latitude with trees located as shown in Figure 4.2 Scenario A1) cast shadows illustrated here for three dates and times: January 21 3:00 pm CST (top), March 21 4:00 pm CST (center), and July 21 5:00 pm CDT (bottom). These times of day solar gain is greatest on the west side of the home. These illustrations show two building walls (facades) of the home: the west facade is to the left and the south facade is to the right. These shadow patterns indicate that this tree placement allows winter solar gain on the south and most of the west (top) and in summer the trees shade the west. Although at this time of day in summer, the south side of the building is shaded by the roof overhang. However, the trees cast shadows on the home in March at a time when solar gain is still important for home heating.

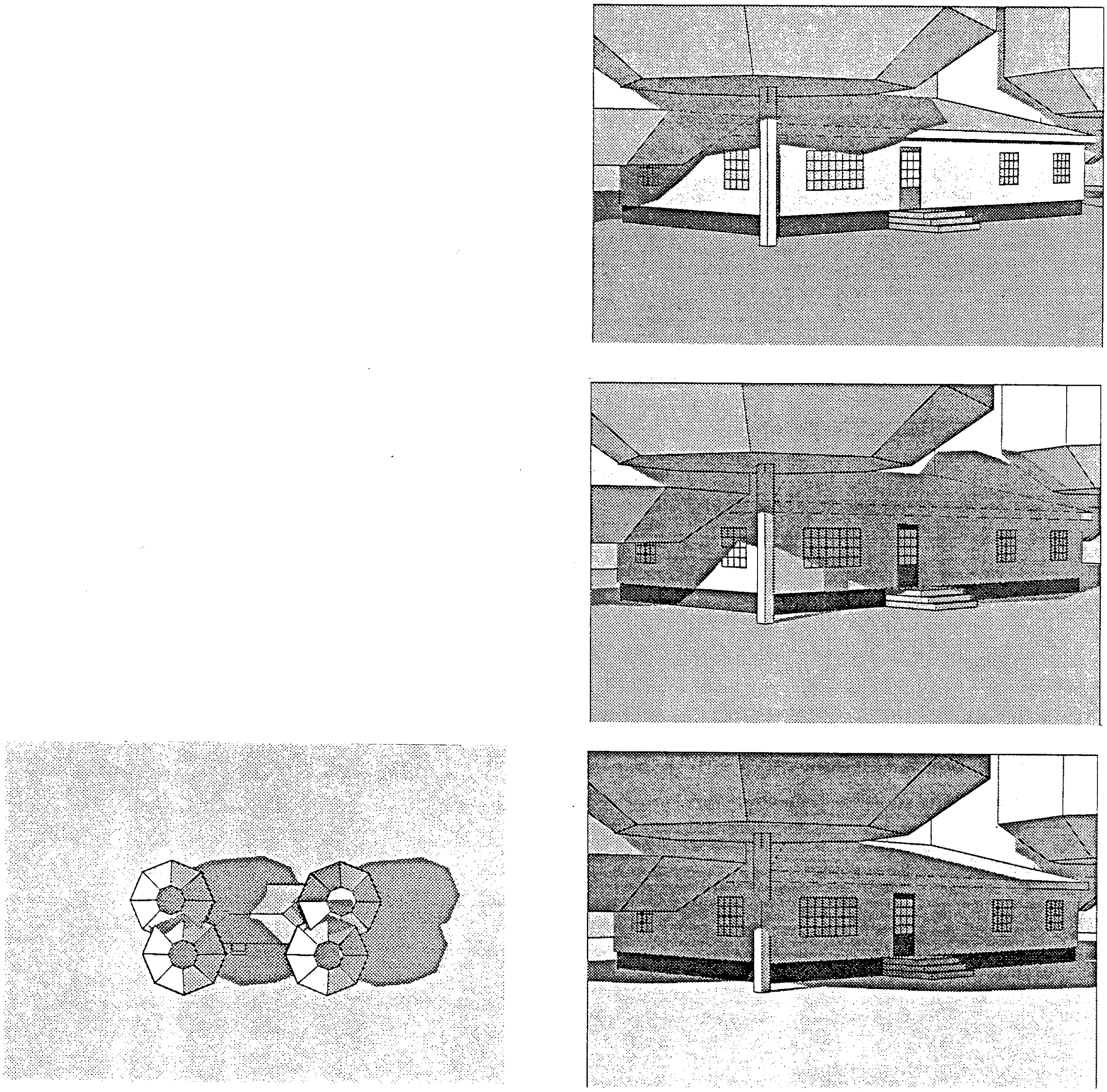


Figure 4.4. Shadow patterns from forty foot tall trees on an east-west home
The same four trees as shown in Figure 4.3 are now forty feet tall in this series of illustrations. The dates and times are the same and some variations in shadow patterns can be seen. As these hypothetical trees have grown from 25 foot to 40 foot tall, the lowest limbs of the two southerly trees have been pruned higher. This allows more sunlight to pass under the tree, such that on January 21 at 3:00 pm (top) two southwest windows are now in full sun and the home benefits from the increased solar gain. While less difference is seen in March (center), the larger trees provide more complete shade on July 21 5:00 pm (bottom).

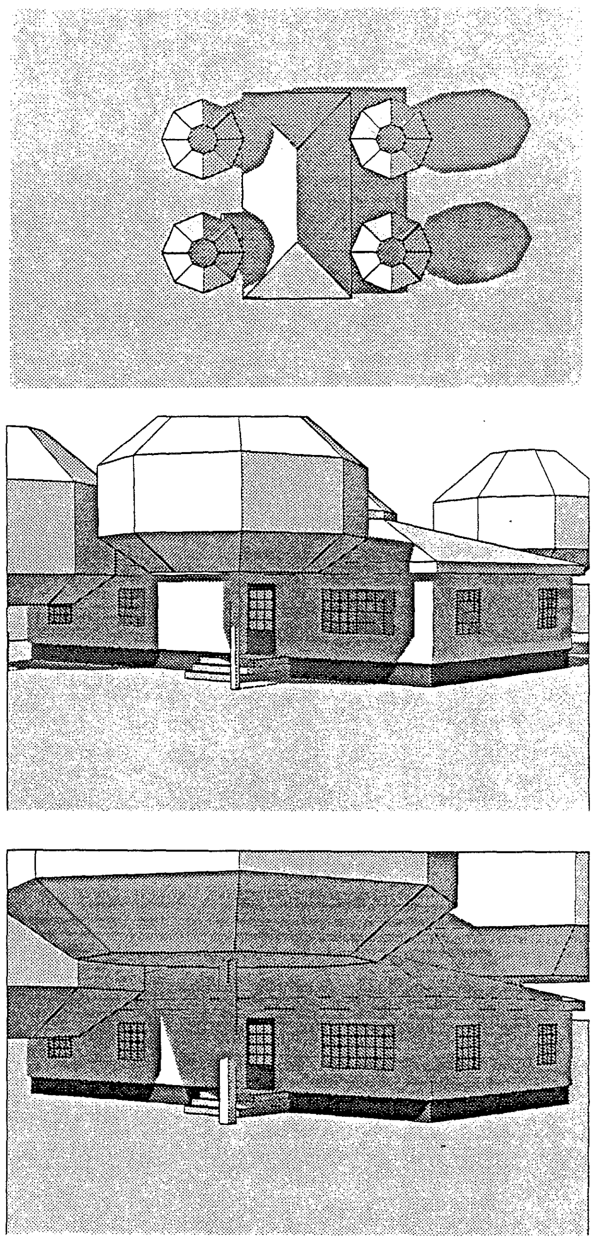


Figure 4.5. Tree shadow patterns on a north-south home
Two trees next to the west facade of a north-south home (at the Twin Cities latitude with trees located as shown in Figure 4.2 Scenario B3) cast shadows illustrated here for July 21 5:00 pm CDT. The solar gain is greatest at this time on the west side of the home and it coincides with the time for peak air conditioning and electrical use. At this time and for this particular tree-window combination, the 25 foot trees (center) are completely effective in blocking unwanted solar gain from the windows. The 40 foot trees (bottom) are more effective in blocking solar gain on the whole west facade of the home.

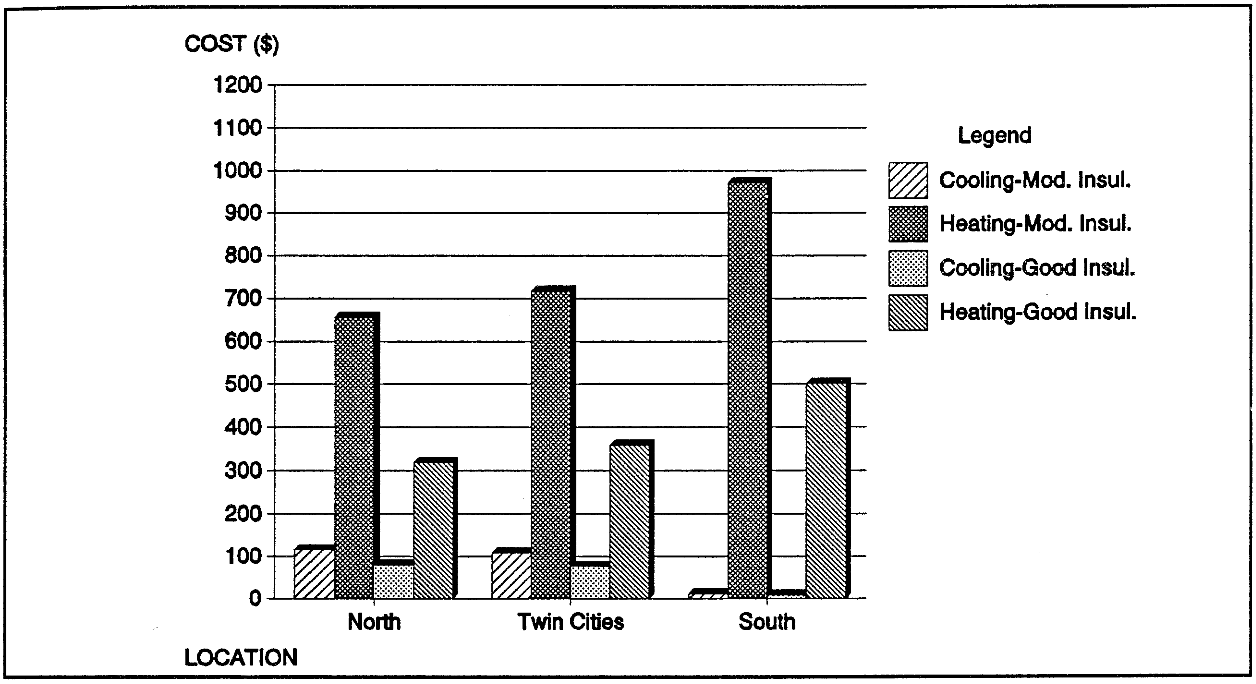


Figure 4.6. Cooling and heating costs for test homes in three locations in Minnesota

2. *Energy Use Simulation Results*

The relative amounts spent on heating and cooling for the east-west oriented test buildings without trees (see Figure 4.6) reveals how important both insulation and heating fuel costs are to Minnesotans. Annual costs are projected to be almost twice as much to heat the moderately insulated home as to heat the one with good insulation given the assumptions of this study. Heating and cooling the same structure to the same temperatures are similar between the Twin Cities and the southern edge of the state because of the heat island effect. Heating the home at the two southern locations would cost 3.9 to 6.6 times the cost for cooling during the year ($319 to $718 for heating and $77 to $116 for cooling). In contrast, at the northern edge of the state (represented by International Falls), the weather may not warrant installation of air conditioners. If used to cool and heat the test homes to the same indoor temperature as the southern locations, heating would cost $502 to $972 annually and cooling would cost only $9 to $12. That is, the owner of a hypothetical home with good insulation would pay 56 times more for heating than air conditioning and for a moderately well insulated house would pay 81 times more for heating than air conditioning to the same level. Results for the north-south test buildings were similar.

Prior to discussing the benefits from trees quantified in this study, caution is urged in applying these figures beyond this study because they only consider benefits from tree shade on windows and only for a single type of house. As stated previously, other studies indicate that shading may only represent 10 to 30 percent of the potential energy savings from trees (Huang et al. 1987).

The effects of tree shade on the energy use of the test buildings were determined (see discussion below). This information can be interpreted to represent the effects of existing situations in which 10 foot, 25 foot or 40 foot tall trees exist in the same positions relative to a similar home. Also, these results could indicate a hypothetical "end result" after trees of those ultimate heights matured. For this research, these figures were used in the following economic analysis to calibrate energy and carbon benefits as trees grow over a forty year period.

For the buildings studied, the magnitude of energy use differences between the north-south and east-west oriented buildings was about the same as the magnitude of differences between buildings with and without tree shade. That is, the base heating and/or cooling costs were always found to be lower in the east-west building than in the north-south building. This exemplifies the importance of winter solar gain on the south facade and the penalties of summer solar gain on the west and east facades. For the tree locations tested the energy costs were not only lower for the east-west home, but the savings from tree shade were somewhat greater.

Several examples from the data illustrate the extent of potential benefits from tree shade on windows in southern Minnesota. (The pairs of figures are results for the Twin Cities and Sioux Falls tests.) First, consider the cooling and annual benefits associated with the existence of four 25 foot tall trees next to a home in southern Minnesota. For a moderately insulated east-west oriented house, these trees would yield annual air conditioning savings of $23 to $25 (21 percent savings). The same trees along a moderately insulated north-south oriented house would save $18 to $21 (16 percent savings) over the year. In both examples, the trees would substantially increase heating costs. So, the annual net savings for the east-west home would be $6 to $8 (about a 1 percent savings). The north-south configuration tested would yield an annual heating and cooling utility savings of $10 to $12 (1 to 1.5 percent savings).

The same annual comparisons can be made for the four 40 foot trees in southern Minnesota. This might be equivalent to moderate size elms and oaks located to the east and west of a one story home. Air conditioning for the moderately insulated east-west home would be reduced $34 to $37 (31 to 32 percent savings) from the four trees. Air conditioning for the moderately insulated north-south home would be reduced $25 to $27 (20 to 21 percent savings). However, these savings would be reduced because of increased heating costs from blocked winter solar gain. Thus, annual combined savings for heating and cooling costs for the east-west home would be $8 to $9 (just over a 1 percent savings). Similarly, the combined utility savings for the north-south home would be $13 to $14 (nearly a 2 percent savings).

In each of these scenarios, the trees benefit the environment by directly removing atmospheric carbon dioxide as well as by reducing carbon dioxide emissions from reduced fuel and electrical consumption. Specifically, in southern Minnesota, due to energy savings from window shade alone, four trees planted near the test homes would result in reduced emissions of 22 to 63 pounds of carbon per year.

3. Economic Benefits and Energy Savings

The above analysis examined the benefits of trees at fixed points in time. Additionally, people who may want to invest in trees are likely to be concerned with costs associated with planting trees as well as the length of time needed before benefits occur. This cost benefit analysis will discuss several of the tree-building combinations analyzed in this project. Results from the east-west configuration (A1) with four trees and the north-south configuration (B1) with two trees on the west side of the house are compared (see Table 4.1). The B1 landscape was chosen for comparison with the east-west configuration because it provided the best overall results among the north-south configurations. This is appropriate because the objective of analyzing more than one landscape design is to identify which one is best. Results are also presented which compare the different planting schemes within the north-south configuration (see Table 4.2). The reader is encouraged to review the additional data contained in Appendix B.

The effects of tree shading on utility costs and energy conservation are distinctly different between the northern location (International Falls) and the Minneapolis/St. Paul and southern (Sioux Falls) location. Because this study only quantifies the impact of shade, no utility savings are projected for any landscapes, orientations, or insulation levels for houses located at the northern latitude (see Table 4.3). Based on only shade effects, utility costs are projected to increase in the northern latitude cases (see Figure 4.7 and 4.8). This is not surprising because shading increases heating costs and reduces cooling costs. At the northern latitude, cooling costs are only a minor component of total home energy costs (see Figure 4.6). However, it must be borne in mind that the results from this study do not consider wind reduction in the evaluations. In a neighborhood with some tree cover, planting impacts on wind will likely provide savings equal to or greater than that for the shading impact. Whether the potential reductions would result in positive net present values (reductions in utility costs large enough to offset the initial tree planting costs) cannot be determined in the present study.

In the Twin Cities and southern location, direct utility costs are reduced for essentially all landscapes, orientations, and insulation levels (see Table 4.3). The lowered utility costs occur almost immediately in most cases (see Figures 4.7 and 4.8). The reductions in cooling costs more than compensate for increases in heating costs. However, an important question for the homeowner is whether these savings are good enough returns given the initial costs of obtaining the trees.

For the east-west configuration with four trees (see Table 4.1), the NPVs are positive (i.e. the trees pay for themselves) only when the discount rate is low (0 percent) and small trees are planted. In the other situations, the trees do not pay for themselves. If fewer trees had been planted for the east-west oriented house, however, it is likely that the results would

Table 4.1. Present values of utility savings minus tree costs for houses oriented in a north-south or east-west direction using three alternate rates of return

	East-West (A1)			North-South (B1)		
	0%	4%	10%	0%	4%	10%
NL/SW (mod insul.)	-808	-420	-373	-239	-148	-137
(good insul.)	-541	-312	-285	-109	-93	-91
NL/BB (mod insul.)	-1190	-783	-732	-410	-316	-304
(good insul.)	-898	-658	-628	-270	-253	-251
TC/SW (mod insul.)	137	-34	-55	218	50	28
(good insul.)	223	1	-26	218	50	28
TC/BB (mod insul.)	-158	-334	-357	79	-95	-117
(good insul.)	-65	-295	-324	79	-95	-117
SL/SW (mod insul.)	105	-45	-63	228	56	34
(good insul.)	142	-29	-51	291	83	56
SL/BB (mod insul.)	-198	-351	-371	89	-88	-110
(good insul.)	-155	-331	-354	155	-58	-86

NL = northern location
TC = Twin Cities
SL = southern location
SW = Small whip
BB = ball & burlap

Table 4.2. Present values of utility savings minus tree costs for the house oriented in a north-south direction and using three alternate rates of return

	B1			B2			B3		
	0%	4%	10%	0%	4%	10%	0%	4%	10%
NL/SW (mod. insul.)	-239	-148	-137	-272	-162	-149	-548	-345	-318
(good insul.)	-109	-93	-91	-143	-107	-103	-264	-198	-191
NL/BB (mod. insul.)	-410	-316	-304	-446	-332	-318	-889	-688	-661
(good insul.)	-270	-253	-251	-307	-269	-265	-596	-526	-517
TC/SW (mod. insul.)	218	50	28	146	16	0.34	268	25	-6
(good insul.)	218	50	28	151	21	5	268	25	-6
TC/BB (mod. insul.)	79	-95	-117	2	-131	-148	-21	-272	-304
(good insul.)	79	-95	-117	6	-128	-145	-22	-272	-304
SL/SW (mod. insul.)	228	56	34	122	8	-6	311	45	12
(good insul.)	291	83	56	200	46	27	356	69	32
SL/BB (mod. insul.)	89	-88	-111	-24	-141	-156	25	-248	-283
(good insul.)	156	-58	-86	56	-101	-121	69	-225	-263

Table 4.3. Present values of utility savings (not including tree costs) for houses oriented in a north-south or east-west direction using three alternate rates of return

	East-West (A1)			North-South (B1)		
	0%	4%	10%	0%	4%	10%
NL/SW (mod insul.)	-648	-260	-213	-159	-68	-57
(good insul.)	-381	-152	-125	-29	-13	-11
NL/BB (mod insul.)	-710	-303	-252	-170	-76	-64
(good insul.)	-418	-178	-148	-30	-13	-11
TC/SW (mod insul.)	297	126	105	298	130	108
(good insul.)	383	161	134	298	130	108
TC/BB (mod insul.)	322	146	123	319	145	123
(good insul.)	415	185	156	319	145	123
SL/SW (mod insul.)	265	115	97	308	136	114
(good insul.)	303	131	109	371	163	136
SL/BB (mod insul.)	283	129	109	329	152	130
(good insul.)	326	149	126	396	182	154

NL = northern location
TC = Twin Cities
SL = southern location
SW = small whip
BB = ball & burlap

Figure 4.7. Annual utility savings over time for three locations for the house oriented east-west with good insulation and four small trees.

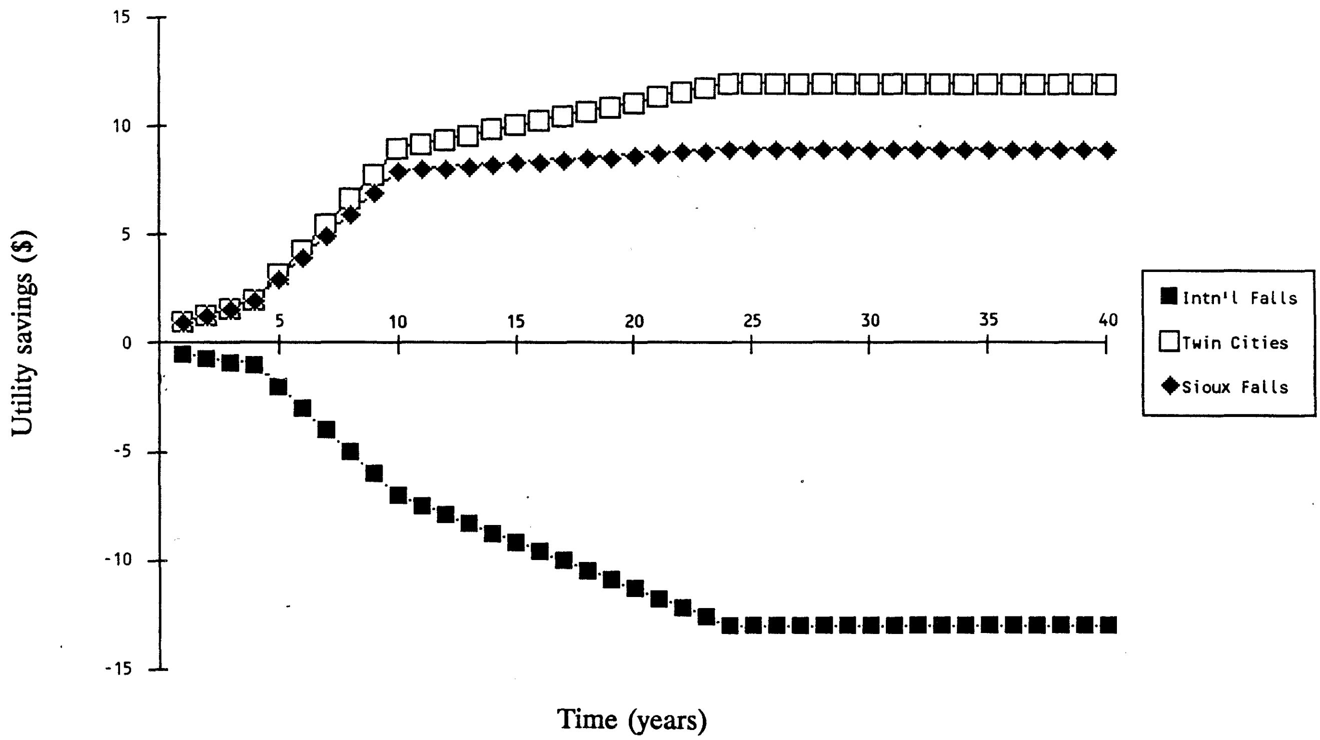
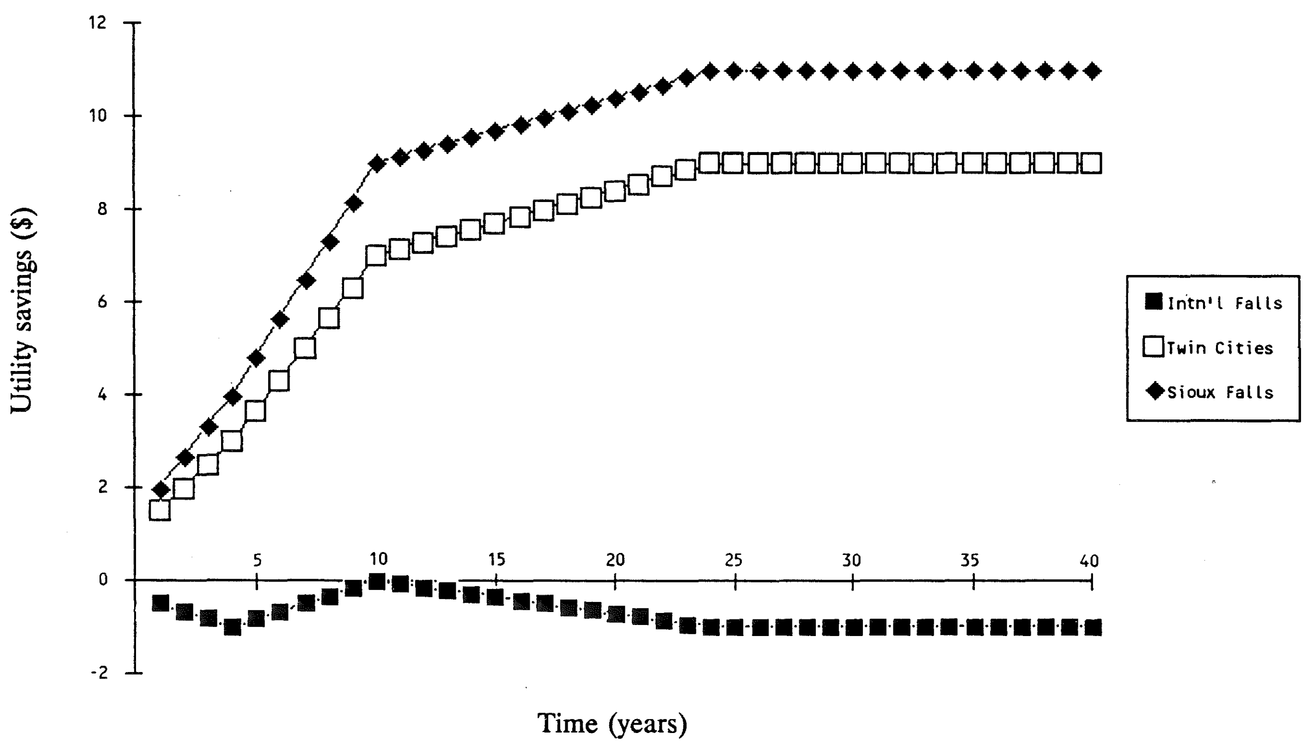


Figure 4.8. Annual utility savings over time for three locations for the house oriented north-south with good insulation and two small trees to the west.



have been more positive and would have reflected the results for Landscape B1.

In general, the NPVs are positive for all discount rates when the smaller trees are planted adjacent to the north-south oriented house (see Table 4.1). Where the larger trees are planted NPVs are only positive when the discount rate is near zero percent. Utility savings at a given point in time are larger with the larger trees, but the NPVs are much lower because the increased benefits do not outweigh the increased costs. As a society, it may not be desirable to subsidize the full costs of planting the larger trees, but homeowners may be willing to pay the additional costs because of other benefits not included in this analysis.

In general, benefits are greater or losses smaller for Landscape B1 than for Landscape B2 (see Table 4.2). These results clearly indicate that when two trees are to be planted near a north-south oriented house, utility and carbon benefits are greater if the trees are planted on the west side rather than on the east side. Comparisons between Landscape B1 and Landscape B3 are more variable, but in general Landscape B3 had lower NPVs than Landscape B1 because the higher cost of planting four trees rather than two was not justified by large enough increases in benefits. This is especially true for higher discount rates.

Cumulative carbon effects are positive in all cases (i.e. net emissions were reduced or at least offset by the increased carbon sequestration by the trees) (see Table 4.4). Reductions in total emissions over 40 years range from 1/10 ton per house in the northern location to over three tons per house in the southern location. As might be expected, the biggest reductions in net CO_2 emissions occurred for houses with four planted trees (Landscapes A1 and B3) compared to houses with two trees planted (Landscapes B2 and B3).

The cost-price of keeping a pound of carbon out of the atmosphere (or, equivalently, removing a pound) is extremely variable (see Table 4.5). There are several cases where the NPVs of the tree-planting projects are positive without consideration of carbon effects. In those cases, carbon effects are essentially free. For cases in the central and southern latitudes where the present values of utility savings do not cover tree planting costs, the cost-price per pound for carbon runs from less than one cent to 21 cents. At the northern location, the cost price per pound of carbon exceeds $4.00 per pound.

4. *Tree Planting in Rural Areas for Carbon Fixation*

The cost prices of carbon fixation for the well managed mixed-species oak forest and the intensively managed red pine plantation are given in Table 4.6 and 4.7. Results for the other forest types are contained in Appendix B. The biggest factor in determining the cost price of carbon fixation is whether the land rental cost is included in the analysis. For both the mixed-species oak forest and the red pine plantation, the cost-price of carbon is much less than one cent per pound when land rental costs are ignored. The cost price of carbon fixation increases markedly when land rental costs are included in the analysis. The cost

Table 4.4. Reductions in carbon emissions (pounds) over 40 years due to the planting of trees. Reductions reflect both energy conservation and carbon sequestration.

	East-West Configuration	North-South Configuration		
	A1	B1	B2	B3
NL/SW (mod insul.)	319	1188	911	2417
(good insul.)	1596	1587	1324	3026
NL/BB (mod insul.)	250	1272	970	2562
(good insul.)	1650	1697	1412	3216
TC/SW (mod insul.)	4857	3174	2764	5631
(good insul.)	5191	3113	2779	5572
TC/BB (mod insul.)	5192	3392	2957	6020
(good insul.)	5557	3323	2970	5960
SL/SW (mod insul.)	4304	3300	2766	5692
(good insul.)	4902	3368	2830	5772
SL/BB (mod insul.)	4582	3525	2954	6077
(good insul.)	5233	3595	3017	5233

NL = northern location
TC = Twin Cities
SL = southern location
SW = small whip
BB = ball & burlap

Table 4.5. **Cost price ($) of removing a pound of carbon from the atmosphere. Positive values indicate that utility savings do not cover tree planting costs.**

4% Rate of Return

	A1	B1	B2	B3
NL/SW (mod insul.)	2.67	.314	.454	.349
(good insul.)	.465	.143	.200	.159
NL/BB (mod insul.)	4.43	.560	.770	.595
(good insul.)	.847	.334	.429	.363
TC/SW (mod insul.)	.017	-.037	-.014	-.011
(good insul.)	-.001	-.038	-.018	-.011
TC/BB (mod insul.)	.143	.062	.100	.100
(good insul.)	.118	.063	.096	.102
SL/SW (mod insul.)	.025	-.040	-.007	-.019
(good insul.)	.014	-.058	-.039	-.028
SL/BB (mod insul.)	.170	.055	.106	.090
(good insul.)	.141	.036	.074	.081

Table 4.6. Implied price of carbon fixation for well-managed rural mixed-species oak forests in Minnesota (60 year horizon)

Without Land Rental				
Interest Rate	Site Index			
	Poor	Fair	Good	VGood
0 percent	0.002	0.002	0.001	0.001
4 percent	0.006	0.004	0.004	0.003
10 percent	0.007	0.005	0.004	0.004

	With Land Rental			
Interest Rate	Site Index			
	Poor	Fair	Good	VGood
0 percent	0.049	0.037	0.031	0.026
4 percent	0.053	0.040	0.034	0.030
10 percent	0.055	0.041	0.035	0.031

Table 4.7. Implied price of carbon fixation for pure red pine plantations in Minnesota with initial stocking of 800 trees per acre. (60 year horizon)

	Without Land Rental	
Interest Rate	Site Index	
	60	70
0 percent	0.001	0.001
4 percent	0.005	0.004
10 percent	0.007	0.005

	With Land Rental	
Interest Rate	Site Index	
	60	70
0 percent	0.014	0.011
4 percent	0.024	0.017
10 percent	0.028	0.020

increases to several cents per pound of carbon for both oak and red pine.

In the urban areas where tree planting pays for itself and carbon benefits are free, the implied cost of carbon is generally lower than that found for the rural area. In these situations, urban plantings are a better option than rural plantings. But where the carbon benefits are not free, the cost-price for carbon fixation tends to be higher in the urban areas than in the rural areas. This is particularly true in the northern part of the state. Given the data available at this point, rural plantings may be the preferred option in northern Minnesota.

5. *Comparison of Results between the Current Project and Other Energy Conservation Planting Research*

This project and similar studies attempting to quantify benefits of trees face a difficult challenge. Computer models to estimate the impacts of trees on building energy use are still relatively crude. Because of the uncertainty involved in the results, comparing the results of this project with similar nationally recognized studies is useful. Table 4.8 summarizes the current study along with two comparable studies done at Lawrence Berkeley Laboratory (LBL) and one by McPherson. Notable differences exist between the results of these studies. These differences can be attributed to variations in the assumptions and the scope of the work. Furthermore, other studies have not considered an environment as extreme as International Falls.

All four of these studies have used computer simulation to evaluate the potential of tree shade to reduce residential energy costs. In contrast to the current work, the other three also projected benefits from wind reductions by trees. Importantly, Huang *et al.*(1987) states the expectation of the LBL researchers that direct shading only accounts for 10 to 30 percent of the benefits associated with energy conservation plantings with most benefit being derived from temperature change due to evapotranspiration. The 1990 LBL study finds that for the Twin Cities, the benefits during the heating season from wind shielding are 4 to 7 times greater than the penalties due to shading. The McPherson study suggests savings in Madison during the winter from wind reduction ($63 or 11 percent) comparable to the negative benefits (increases in fuel cost) from winter shading ($59 or 10 percent). However, the benefits from wind shielding and temperature change cannot be attributed solely to planting of trees on an individual property. They assume significant community wide tree planting such as an increase in tree cover by 30 percent throughout an urban area (LBL studies).

Another significant difference in the assumed tree characteristics between this study and the others is the growth rate and costs of trees. The LBL work assumes trees costing $5 to $60 each would mature in ten to seven years, respectively. In this project, measurement of trees of known age and current market rate costs of trees led to the assumptions that tree stock costs $40 to $120 and that these trees would reach a height of 25 feet in ten to seven years, respectively, and a height of 40 feet in 24 to 21 years, respectively. Many other Minnesota species typically cost more and grow more slowly than the test trees. These differences in costs have a bearing on the potential cost effectiveness of tree planting for energy conservation.

Comparison of the fixed-in-time annual benefits shows both similar and different results between this project and the LBL work. For this comparison, Table 4.8 lists the results of this project for four 25 feet tall trees. For the Twin Cities, tree shade is predicted to reduce annual cooling costs in the earlier LBL studies by 27 to 36 percent, while in this project (for the same latitude and house orientation) reductions are 21 to 23 percent ($18 to $23). Similarly, the 1990 LBL study finds a 21 to 22 percent reduction in Twin Cities cooling costs from three 25 feet trees. When combining the effects of winter and summer window shade only for four trees at the Twin Cities location near a building with east-west orientation, this project finds an annual savings of 1 to 2 percent ($8 to $9). For similar circumstances, the 1990 LBL study finds a shading benefit of up to $1, but a combined shade and wind shielding benefit of 8 percent ($48 to $81).

TABLE 4.8. Summary of the current project and three other studies

CURRENT PROJECT

The benefits quantified only include those from shading windows. For comparison purposes, listed below are the effects of four 25 foot tall trees per home. The ranges in results represent variations due to home insulation level, building orientation, and location (northern versus southern Minnesota).

Heating "Benefits" (Fuel Cost Change)	$ -19 to -5
Cooling Benefits	$ 4 to 25
Total Benefits	$ -3 to 12

LAWRENCE BERKELEY LAB (EARLIER STUDIES) - Akbari *et al.* 1986-88.

The benefits quantified include impacts on electrical use for cooling resulting from shade on the building and from wind reduction. The results listed here are for three trees per home under Minneapolis weather conditions. The ranges in results represent variations due to building insulation level.

	Annual Cooling	Summer Peak
Benefits due to Shade	27.3% to 36.3%	23.1% to 29.1 %
Benefits due to Wind	-18.9% to -22.1%	-1.9% to 0
Shade + Wind Benefits	8.4% to 14.5%	22.0% to 29.11%

LAWRENCE BERKELEY LAB (1990 STUDY) - Huang, Akbari, Taha 1990.

The benefits quantified include impacts on annual heating and cooling resulting from shade on the building and wind reduction. The results listed here are for three trees per home under Minneapolis weather conditions. The ranges in results represent variations due to building insulation level. The first three rows of data represent the level of change in fuel used, while the last row represents the percentage of change.

	Annual Heating	Annual Cooling	Total Energy
Benefits from Shade	-3.6 to -4.1 MBtu	316 to 381 kWh	$-1 to 0
Benefits from Wind	9.5 to 15.4 MBtu	-22 to -30 kWh	$49 to 81
Shade + Wind Benefits	5.9 to 11.3 MBtu	286 to 359 kWh	$48 to 81
Shade + Wind (% Change)	6.1% to 6.8%	18.5% to 19.7%	7.9% to 8.1%

MCPHERSON - McPherson, Herrington, Heisler 1988.

The benefits quantified include impacts on annual heating and cooling resulting from shade on the building and wind reduction. The results listed here are for a hypothetical 40 percent shade during the heating season and 80 percent shade during the cooling season evenly distributed over the home and for a hypothetical 50 percent wind reductions; both applied under Madison, Wisconsin weather conditions.

	Annual Heating	Annual Cooling
Benefits due to shade (80% summer, 40% winter)	$- 59 (-10%)	$25 (31%)
Benefits due to 50% wind reduction	$63 (11%)	$20 (25)

C. Guidelines for Planting for Energy Conservation in Minnesota

The following guidelines are for planting for energy conservation in Minnesota. They are derived from the results of this study and other research which applies to Minnesota. The guidelines are primarily for single family houses, but can be applied directly to other lowrise structures. The relative importance of different planting schemes is indicated in Table 4.9. Neighborhood scale illustrative plans show generally what a combination of all the recommendations may mean for the public and private planting. While the plantings suggested here are expected to conserve energy, an economic analysis could not be performed with current information to determine their overall cost effectiveness.

1. Shade for Summer Cooling and to Reduce Air Conditioning Demand

a. Shade West Window. Highest priority should be given to planting deciduous trees which will shade west facing windows during June, July, and August. This will reduce energy use in air conditioned structures, increase comfort in non-airconditioned structures, and reduce peak electrical consumption. Windows facing due west receive the most solar gain between 3:00 pm and 7:00 pm (CDT). Therefore, priority should be given to locating trees on the west which will attain heights of 25 feet or more. Trees with low limbs and/or large shrubs should also be planted to the northwest of the windows if other trees and buildings do not block late afternoon sun. For most types of insulated construction, sun warmed walls also heat the inside of the building. Therefore, shading west facing walls will also be beneficial (see Figure 4.9).

b. Shade East Windows. East facing windows and walls receive the same solar gain in the morning that the west oriented ones receive in the afternoon. While peak daily temperatures and peak air conditioning demand give priority to afternoon shade on the west, simulations of energy use indicate that shading the east is nearly as important. In the summer, windows facing due east receive the most solar gain between 7:00 am and 11:00 am (CDT). Therefore, taller trees (maturing at over 25 feet tall) should be planted to the east and if needed, lower branched trees and/or large shrubs should be planted to the northeast of the windows. Additionally, as with the west, consideration should also be given to shading east facing walls.

c. Shade Air Conditioners. Air conditioners (i.e. window units and outdoor condensers) should be located to the north or east (or less favorably, to the west) of the structure to permit shading by trees. Tall to medium height shade trees should be planted to the south, southeast, or southwest of the air conditioner. The lower branches of any nearby trees should be pruned to a height of at least several feet above (or away from) the air conditioner to permit necessary air flow around the unit. Shrubs should not be planted near the air conditioner because blocking air flow will reduce air conditioner efficiency.

Table 4.9. Impacts of vegetation on energy conservation in Minnesota

Use Of Vegetation	Heating Benefit	Cooling Benefit	Peak Cooling Benefit
Shading: trees on the west	-	+ + + +	+ + + + +
trees on the southwest	- - -	+ + +	+ + +
trees on the east	-	+ + +	o
trees on the south	- - - -	o	o
tree shade on AC unit	o	+	+ +
shade on pavement	o	+	+
Wind Shielding:			
tree cover @ 25%	+ +	o (may be -)	o (may be -)
tree cover @ 75%	+ + + +	o (may be -)	o (may be -)
on site windbreak[1]	+ +	o	o
on site shelterbelt[1]	+ + + +	o	o
Community Climate Change (increased biomass for evapotranspiration effects) with 30% tree cover increase citywide	o	+ + + + + + +	+ + + + + +

[1] may include shrubs and trees

This chart is based upon interpretation of the results of this study and research conducted elsewhere which may apply to Minnesota. The number of "+"s indicate the relative positive benefit vegetation (particularly trees) is likely to have on energy conservation (i.e. savings in energy). The number of "-"s indicate the relative negative benefit vegetation is likely to have on energy conservation (i.e. increased uses of energy). The relative number of "+"s and "-"s might best be considered rankings (i.e. a factor with seven is expected to have greater impact than one with six. However, they do not have quantitative value. The "o" indicates no expected relationship between vegetation and energy conservation. Many of these values have not been quantified for Minnesota conditions and caution should be exercised in use of this chart.

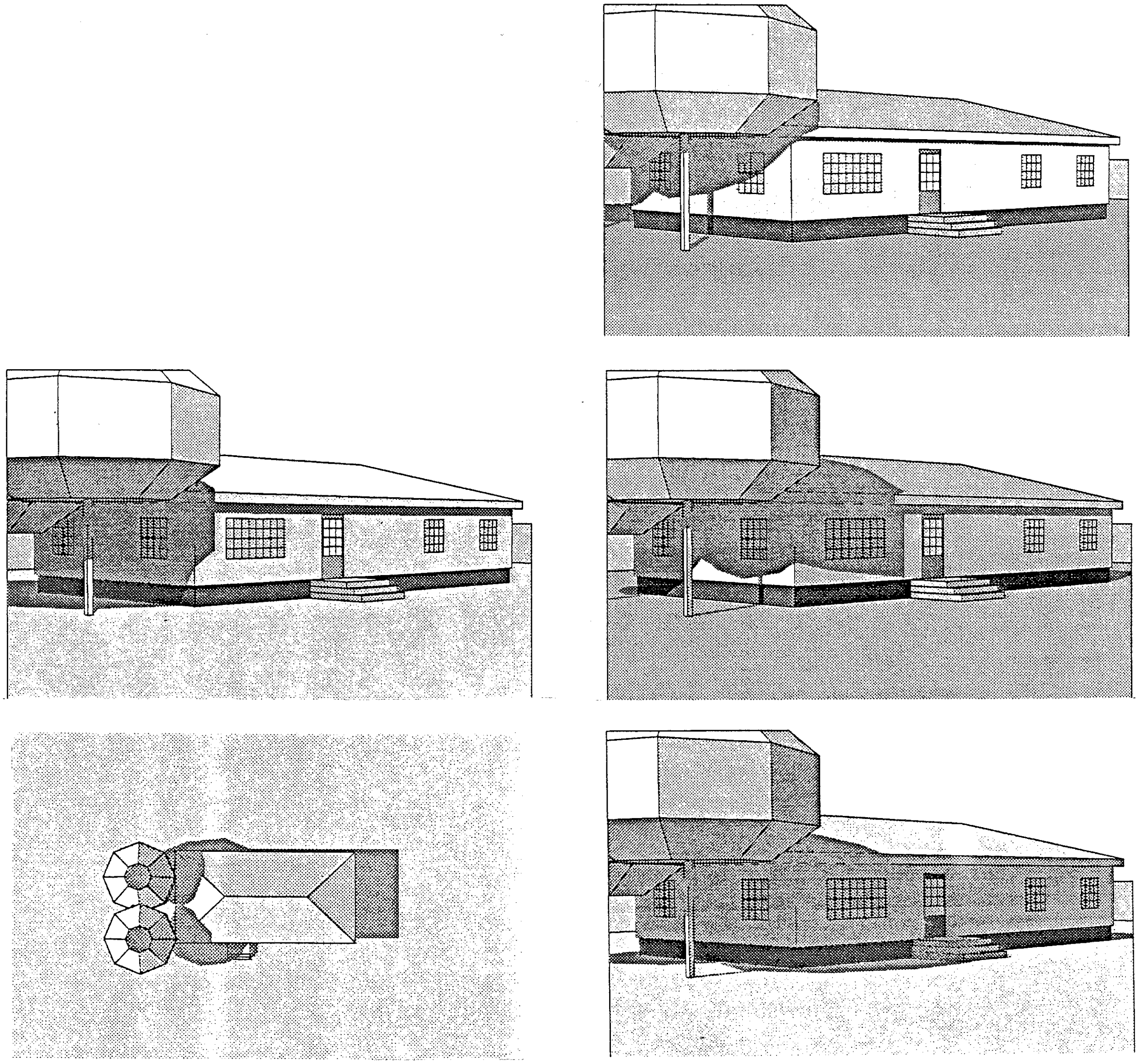


Figure 4.9. Trees located to shade a west wall
To achieve beneficial shade on the west wall of an east-west oriented test building trees could be placed as illustrated in this figure. The west and south facades are shown. Two 25 foot tall trees are shown 12 feet away from the house. The lower limbs of the more northerly tree are kept low (7 feet from the ground) to block late afternoon summer sun from the northwest. Complete late afternoon shade is achieved on the west facade, as shown in the lower plan and perspective drawing with tree shadows at 3:00 pm. on July 21. The lower limbs of the southernmost tree are pruned up to 14 feet above the ground to allow more beneficial solar gain in late winter, as shown in the center drawings of 2:00 and 3:00 pm on March 21. Also, the trunk of the southern tree is aligned with the south facade of the house to minimize shade in midwinter, as shown in the top illustration depicting 3:00 pm on January 21. Shadows illustrated here are for a Twin Cities location, but when trees are planted so close to the west side of a structure, the shading patterns for other Minnesota locations are fairly similar.

d. Shade Paved Areas. Trees should be planted to directly shade paved areas (e.g. driveways, parking lots, and paved patios) and/or planted between paved areas and buildings depending on the following circumstances. Sunlight striking dark surfaces such as dark asphalt will be absorbed, thus heating the air and contributing to the urban heat island and also reradiating heat to adjacent buildings. Sunlight striking more reflective surfaces including clean, white concrete can reflect the solar gain to adjoining buildings. If sunrays strike tree foliage rather than a dark paved surface or catch the reflected light before it strikes the building, the solar gain will be dissipated through evapotranspiration rather than increasing air conditioning demand. Therefore, deciduous trees placed west or overhanging dark paved areas will maximize shade during summer afternoons while permitting ice melting solar gain in the winter. Trees planted between paved areas and buildings will intercept heat reflected and reradiated from the pavement.

e. Encourage South/Southeast Breezes. To reduce energy use, buildings should be cooled with natural ventilation whenever possible. For most of Minnesota, summer breezes come from the south to southeast. Dense vegetation should be avoided near the windows, wherever these windows can be opened to take advantage of southerly breezes. This suggests pruning branches of trees high to the southeast of structures and/or avoiding dense shrubs to the south and southeast of openable windows.

2. *Allow Winter Solar Gain*

a. Avoid Planting Trees to South which Shade Windows. During the heating season (September through March), solar gain significantly warms structures as it strikes south windows and walls between 9:00 am and 3:00 pm (CST). Trees should not be planted whose crown casts shade on south facing windows during those times. Generally trees should also be avoided which shade south facing walls during that time. In southern Minnesota on flat locations, trees planted due south should be no closer to the structure than a distance of about 2 1/2 times the mature height of the tree to avoid causing shade on first floor windows. In northern Minnesota, trees planted due south should be no closer to the structure than a distance of about three times the mature height of the tree. To avoid shade on south windows, trees planted to the southeast or southwest of south facing windows need to be located a distance of about four times their height from the structure in southern Minnesota and a distance of about six times their height in northern parts of the state (see Figures 4.10 and 4.11).

Existing trees which significantly shade south windows between 11:00 am and 1:00 pm (CST) during solar midwinter (November to January) can also increase heating demand. In these circumstances consideration should be given to thinning (not topping) existing deciduous trees and removing existing evergreen trees. Tall existing trees within about fifteen feet of first-floor south facing windows will be

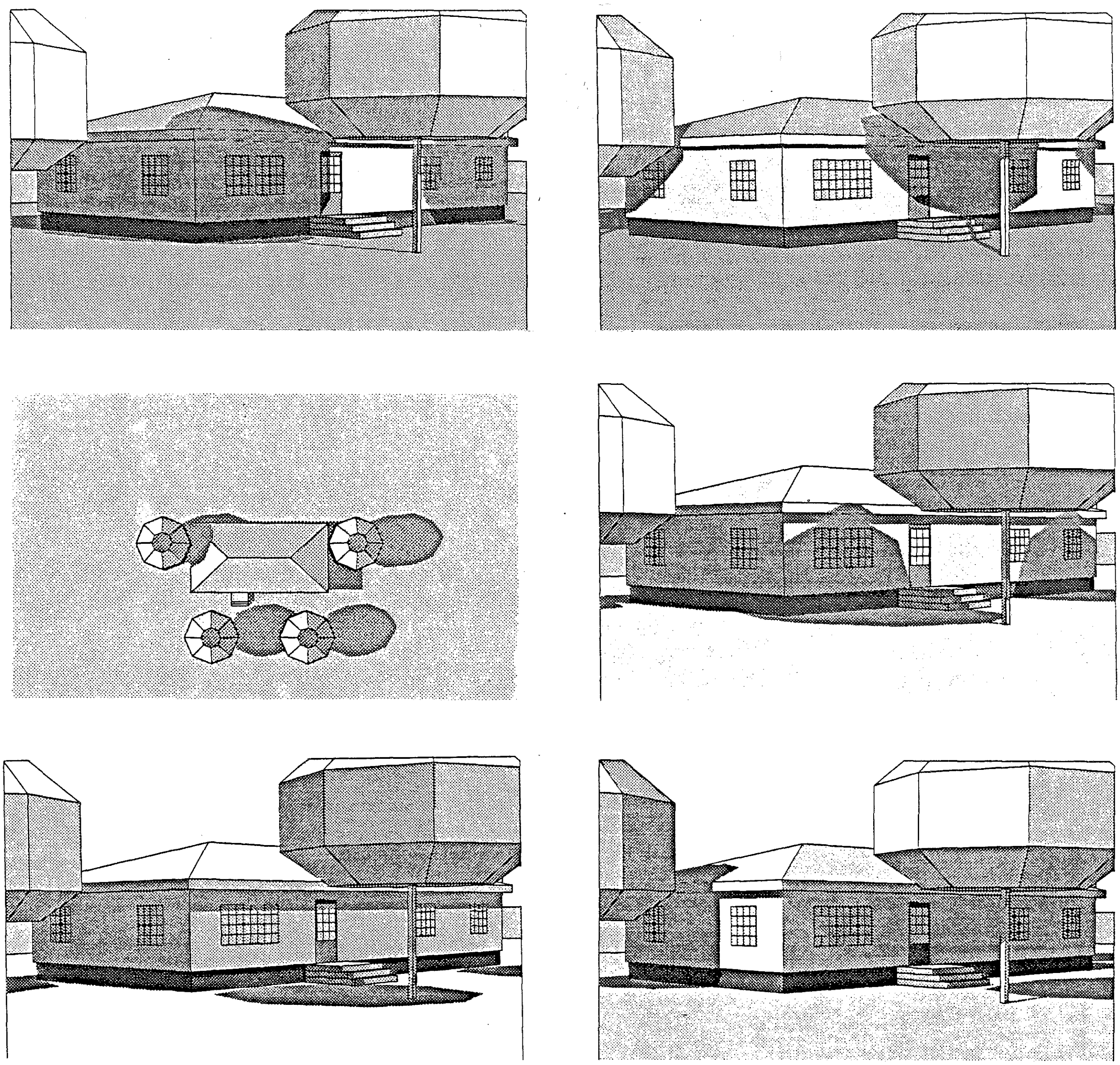


Figure 4.10. The impact of trees twenty feet south of a home
Twenty-five foot tall trees placed with their trunk 20 feet south of a central Minnesota building detrimentally shade the home throughout the winter, as is illustrated for January 21 on the top row with noon at the left and 3:00 pm to the right, as well as on March 21 at noon (center right). Conversely, the shade of these trees misses the home in the summer, e.g. on July 21, both at 1:00 pm (bottom left) and at 5:00 pm (bottom left and plan view).

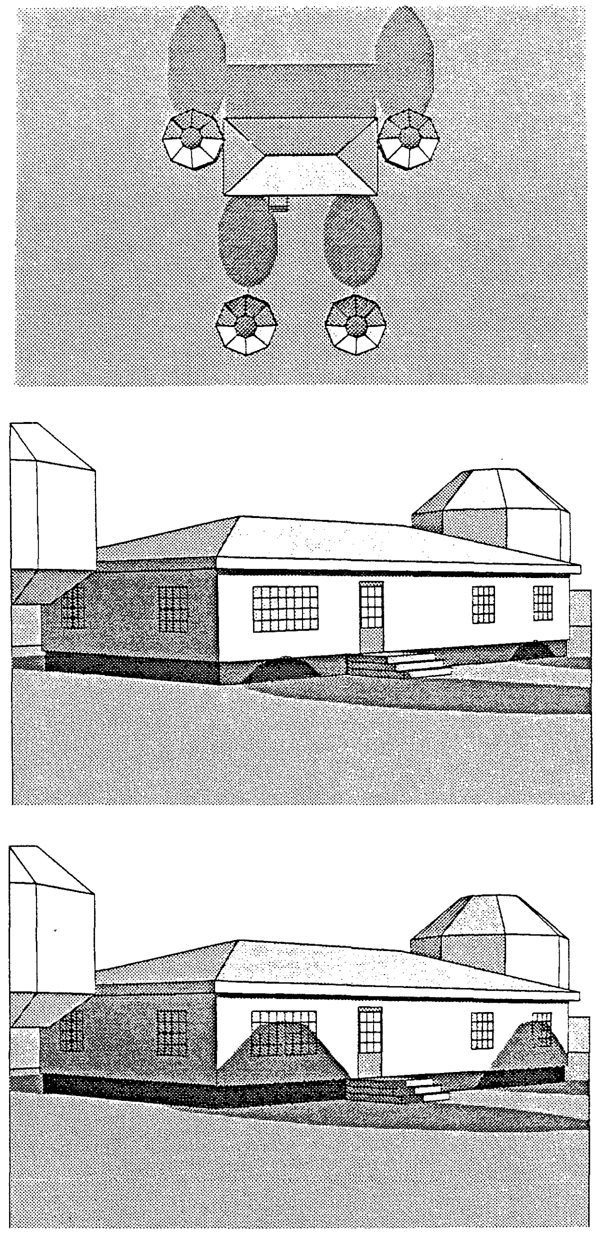


Figure 4.11. Northern and southern Minnesota comparison of trees fifty feet south of a home

The shade of twenty-five foot tall trees placed 50 feet due south of a home cast negligible shade on a home at the southern edge of the Minnesota (center), while the same trees would significantly shade the windows and walls of a home at the northern edge of Minnesota (bottom).

more advantageous if the lower branches are removed, so that midday midwinter sun can shine below the branches.

b. Use Solar Friendly Trees to Southeast and Southwest. In spring and fall solar gain is also important on east facades between 9:00 am and 11:00 am (CDT) in September and 8:00 am to 10:00 am (CST) in March, and on the west facades between 3:00 pm and 5:00 pm (CDT) in September, and 2:00 pm to 4:00 pm (CST) in March (see Figures 4.12 and 4.13). A strategy to enhance solar gain at these times while still providing summer shade is to use "solar friendly" trees in locations which provide shade at these times. For Minnesota, the most solar friendly trees are deciduous species, setting leaves in early May, losing leaves in September, and having sparse branches in winter. In northern areas of the state, trees which leafout later and drop their leaves earlier are particularly important. No "ideal" tree exists and the suitability of most species of trees has not been evaluated. Among the more solar friendly trees in Minnesota are Kentucky coffeetree, walnut, butternut, and ash. Moderately solar friendly trees include sugar and red maple. Among the least solar friendly trees are evergreens and those oaks which retain most of their leaves in winter.

3. *Shield Buildings from Winter Winds*

a. Plant Dense Trees to West and North. In agricultural parts of the state, properly planned shelterbelts on rural sites and on the open western edges of communities should be planted to reduce winter winds and reduce heating costs. In other areas of the state, windbreaks on unwooded locations near buildings in neighborhoods are beneficial. The size of shelterbelts and windbreaks differs, but in both cases priority should be given to selecting trees which will retain their branches (and foliage) to the ground, are fairly stiff, and are reasonably fast growing. The number of trees used and their spacing should optimize plant growth and the retention of low branches. Specific decisions will depend on how soon results are needed and what level of return on investment is desired. Longterm (forty plus years) cost effectiveness will be increased by planting small tree stock further apart. However, larger trees at closer spacing may be justified, particularly in urban settings. Trees planted in rows perpendicular to the prevailing winter wind are most effective. The number of rows of trees planted depends on the amount of room available. To be effective as a windbreak, rows of trees should not be planted so close together that they shade each other sufficiently to cause the loss of lower branches.

On large, open sites where winter winds are strong in the agricultural areas of the state, shelterbelts should be planted north and west of the exposed structures. Typically, shelterbelts are planted more than fifty feet upwind of the structures they shelter and they should extend fifty feet south and east of the structures. Shelterbelts usually feature an upwind shrub row to control snow drifting and up to seven rows of trees (primarily evergreens). For longterm cost

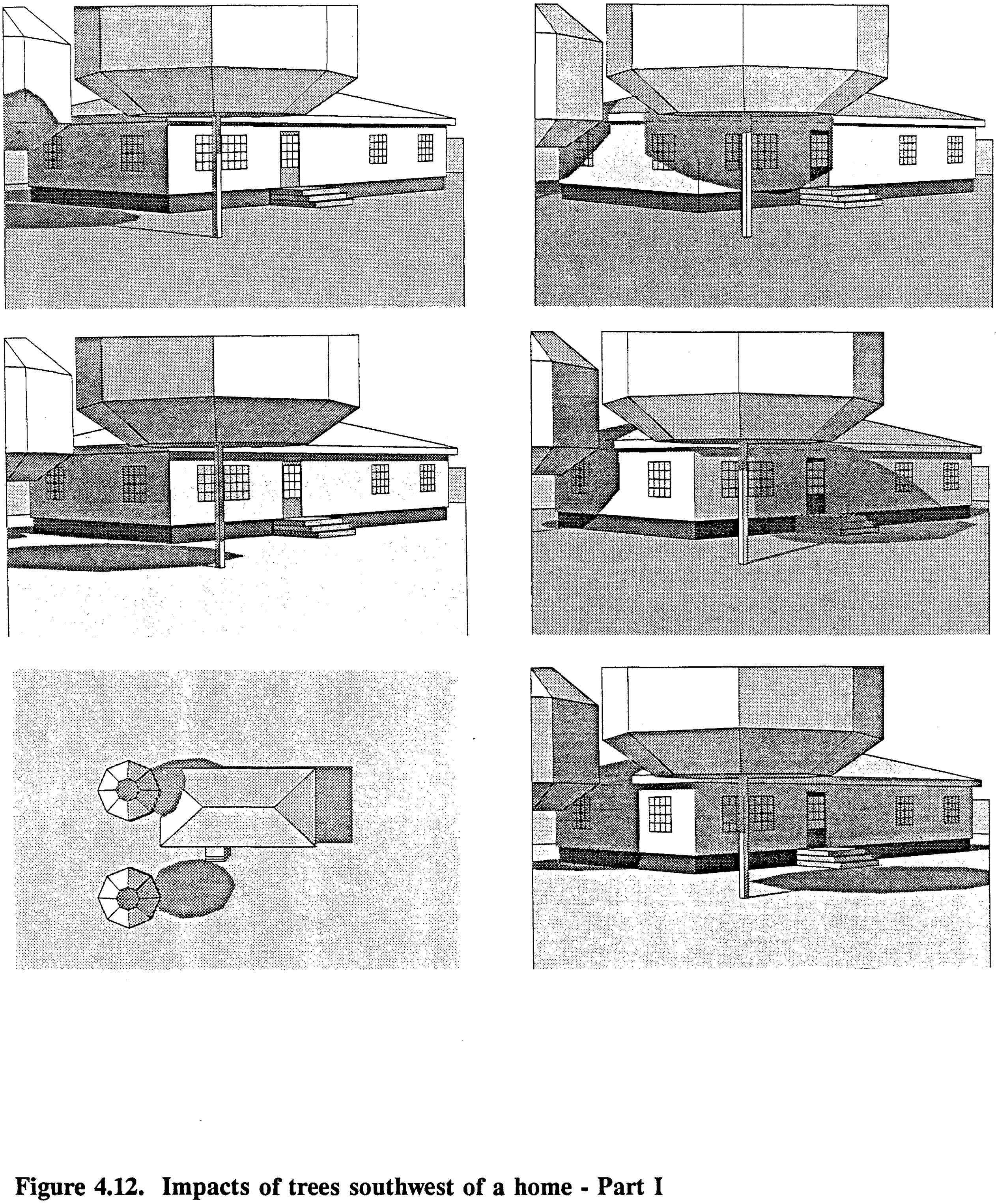


Figure 4.12. Impacts of trees southwest of a home - Part I
A 25 foot tree located southwest of a central Minnesota home (12 feet west and 20 feet south from the southwest corner of the home) does not cast any shade on the home in the summer. July 21 at 5:00 pm is shown on the bottom row. But, the shade of the same tree misses the home at noon in the winter, as shown for January (upper left) and March (center left). However, the tree casts shade on the home in late afternoon, as illustrated on January 21 at 3:00 pm (upper right) and on March 21 at 4:00 pm (center right).

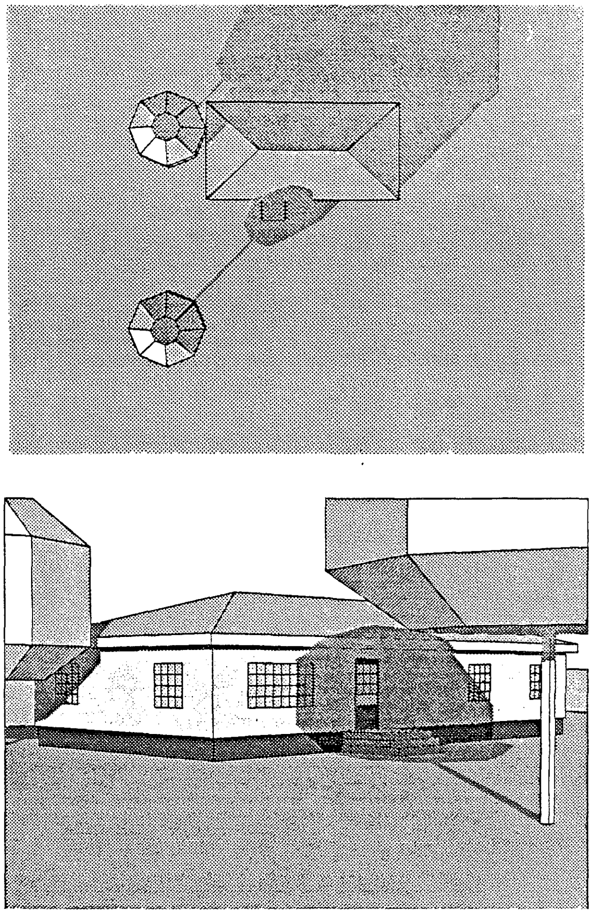


Figure 4.13. Impacts of trees southwest of a home - Part II
Moving the same tree as Figure 4.12 twenty feet further south, so the tree is now 40 feet south of the building, still results in some detrimental shade as indicated for January 21 at 3:00 pm in the plant view and drawing. Specifically, on January 21 at 3:00 pm in the Twin Cities, a 25 foot tall tree has a 110 feet long shadow, while the same tree on December 21 at 3:00 pm has a 140 feet long shadow.

effectiveness, shelterbelt evergreens should be planted twenty feet apart in staggered rows twenty feet apart. Spacing for most deciduous species should have spacing further apart. Species should be selected to optimize growth under particular site conditions (see Figure 4.14).

Vegetative windbreaks of only one or two rows of trees or shrubs are appropriate where winds are less severe and adequate room is not available for a full shelterbelt. On an open, fairly windy site, a properly planted single row of evergreen trees can provide measurable wind reductions and energy saving. When only one row of trees is used for a windbreak, they should be spaced more closely together than a shelterbelt. Evergreens, such as spruce, fir, or Douglas-fir can be spaced 8 to 10 feet apart if the outside of the row receives full sun.

b. Increase Neighborhood Tree Cover for Wind Reduction. Overall neighborhood tree cover should be encouraged. The collective effect of buildings and trees measurably reduces wind from what it would be on a totally open site. The greater the number of trees in the neighborhood, the greater the overall tree cover, and the more effective the trees are in reducing wind. This is true of a deciduous urban forest. Public and private tree planting and preservation of existing trees should be undertaken to aid in wind reduction and reduce heating demand. Priority should be given to maximizing the number and height of trees where that does not compromise needed heating season solar gain (see above). Also, neighborhood shelterbelts should be incorporated into development plans to the north and west of clusters of housing particularly on unvegetated sites (see Figures 4.15 and 4.16).

4. *Increase the Communitywide Urban Forest*

a. Preserve Existing Trees In and Near Urban Areas. In so far as urban forests reduce summer heat island effects, the planting and preservation of trees should be maximized throughout urban areas. Priority should be given to maximizing tree biomass by preserving large healthy trees. An objective may be to achieve 50 percent or more tree cover throughout a community within 20 years of initial community development and tree planting.

b. Maximize Tree Planting and Care. Healthy, actively transpiring trees provide the greatest benefit in moderating the heat island and directly sequestering carbon dioxide (as well as other pollutants). Trees function most effectively and grow faster when they have sufficient water, when urban stresses are minimized, and when they are healthy. Trees should be planted on sites most suitable for plant growth (including parks, undeveloped lands, residential areas, and office parks). Planting of highly urbanized sites may also be necessary to provide communitywide climatic benefits. This may include planting of parking lots, along roads, and in downtown areas. In such cases, more attention is necessary to provide adequate water, soil aeration, drainage, tree protection, and maintenance.

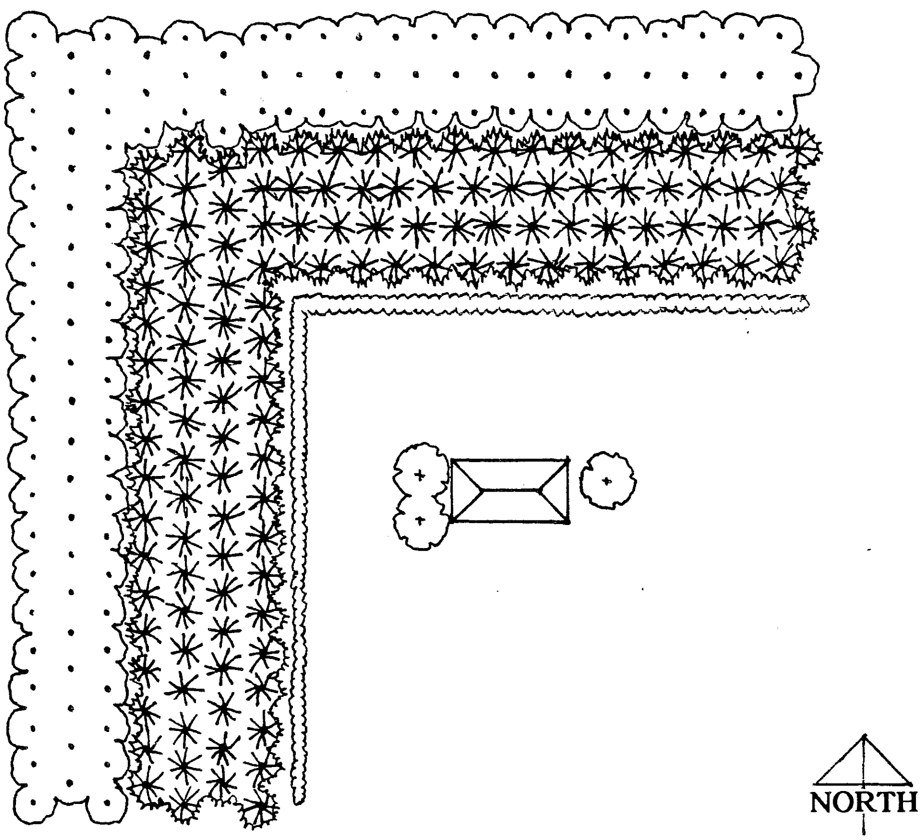


Figure 4.14. Tree locations to provide for an effective shelterbelt
A shelterbelt, such as recommended for farmsteads, will also benefit homes on large lots in open, agricultural areas. The typical shelterbelt shown is 400 feet long on each side with the home set 100 feet from the shelterbelt trees. Starting from the outside (left and top), the first two rows would be a fast growing deciduous tree such as a hybrid poplar. The 3rd row would be a moderately fast growing deciduous tree such as hackberry, ash, or red maple. The 4th through 7th rows would be evergreens, such as Douglas-fir, Norway spruce, and Black Hills spruce. The eight row, a shrub hedge for snow control, could be lilac, arrowwood viburnum, redosier dogwood, or Amur maple. Adapted from Scholten 1988.

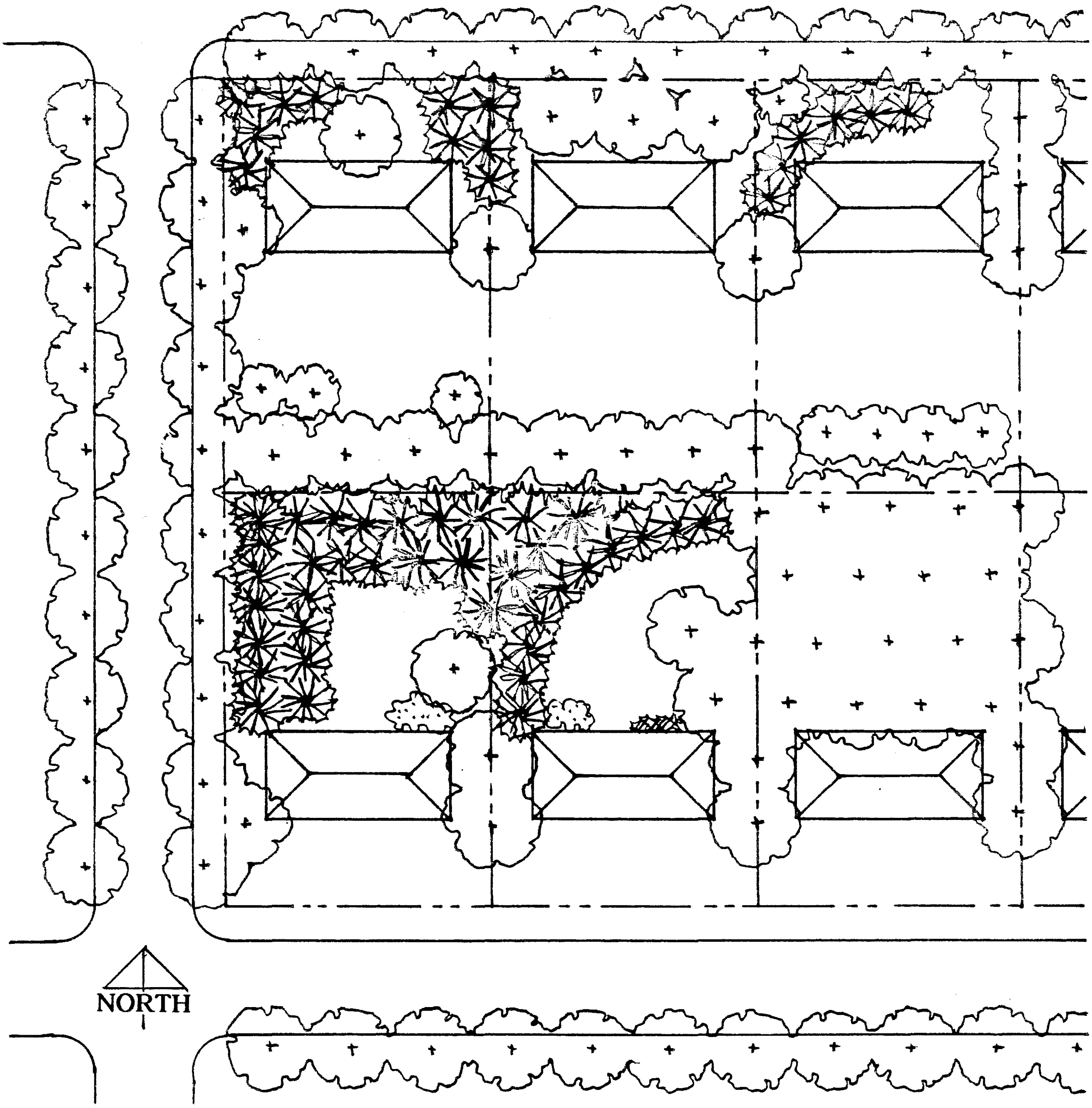


Figure 4.15. Neighborhood scale energy conservation plantings: east-west streets
East-west oriented test homes are shown in the context of a subdivision of 10,000 square foot lots (nearly quarter acre lots). Numerous planting schemes are illustrated which each give priority to allowing solar gain to the south of each home, while including windbreaks and maximizing tree cover.

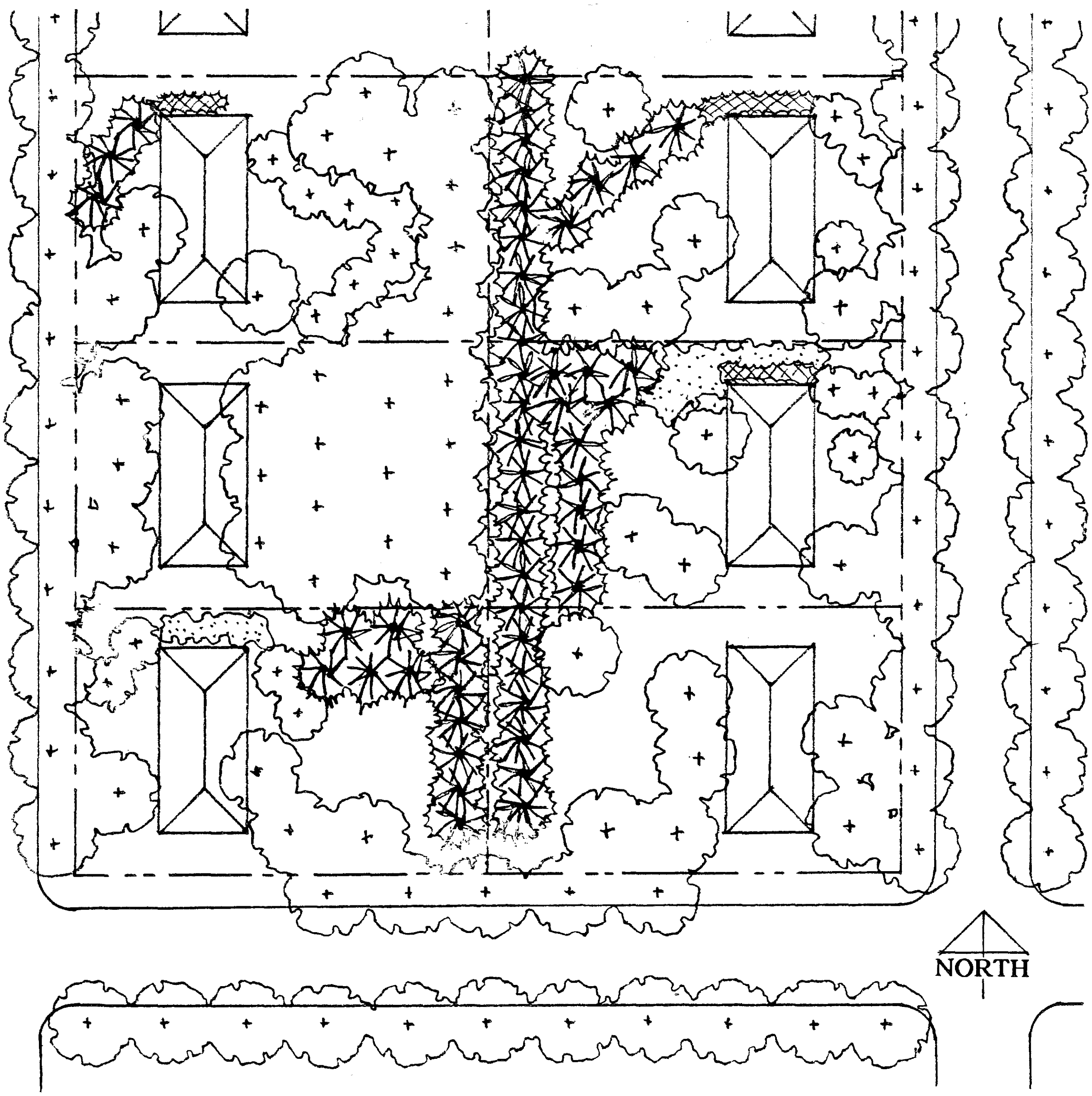


Figure 4.16. Neighborhood scale energy conservation plantings: north-south streets
North-south oriented test homes are also shown in a subdivision of the same density with similar planting priorities. Here the south side of most homes will be shaded in winter by another home to the south. The designs strive to limit any additional winter shade while using short trees and medium height shrubs to shelter the north side of most homes.

D. Recommended Tree Planting Program for Community Trees

To maximize energy conservation benefits, sufficient numbers of trees need to be planted. The size of the program recommended for planting is based on a review of other work which indicates that, to be effective, the tree planting program must be large enough to reduce: 1) the summer temperatures of urban heat islands, 2) wind speeds, and 3) demand for fossil fuels.

1. *Community Tree Survey*

In 1989, a survey of 20 Minnesota communities was conducted by the DNR to assess the condition of the state's urban and community forests, specifically street trees. This survey was done in conjunction with a nationwide survey of 400 communities sponsored by the American Forestry Association (AFA), the USDA Forest Service and the National Association of State Foresters. Small and large communities were surveyed ranging from Kenyon and South International Falls to St. Paul and Minneapolis.

From the survey results, the AFA has estimated that there are approximately 360,000 boulevard trees in Minnesota communities. The survey also found that only 50 percent of the available planting spaces have trees. In other words, the number of trees planted along community streets can easily be doubled, i.e., there is room to plant approximately 360,000 trees along Minnesota community streets.

From earlier nationwide surveys, the AFA has estimated that for every boulevard tree in a community there are ten other trees either on private property (e.g., yards, commercial, industrial) or other public property (e.g., parks, miscellaneous open space). The AFA also has estimated that the average community tree cover is only 30 percent. For maximum environmental benefits (including mitigation of the urban heat island effect), the AFA recommends a 60 percent tree cover in communities.

Applying these numbers to Minnesota, an estimated 3.6 million trees exist in Minnesota communities (360,000 boulevard trees times a factor of ten). Furthermore, sufficient growing space (e.g., boulevards, parks, yards) within these communities for the planting of an additional 3.6 million trees.

2. *Recommended Tree Planting Program*

Based on the AFA survey information, the following minimum annual tree planting program is discussed below. An additional 10 percent of this total (i.e., $720,000) should be provided for public education and technical support of the tree planting program bringing the annual total program cost to $7.92 million. These costs should be considered complimentary to any federal funding through the "America the Beautiful" program which will most likely require matching funds from states and local community participants.

	No. of Trees	Cost per Tree	Total Cost
PUBLIC (streets)	36,000	$120.00	$4,320,000
PUBLIC (parks, etc.)	36,000	$40.00	$1,440,000
PRIVATE (yards, etc.)	36,000	$40.00	$1,440,000
TOTALS:	**108,000**		**$7,200,000**

Recommended costs for this program are based upon a statewide review of tree planting costs as shown in Table 4.10. The range of these costs is due largely to the size of the tree, method of planting, labor used and differences in wholesale and retail prices. Communities will generally be able to purchase their trees at wholesale thereby extending their planting dollars. The use of volunteer labor will also extend public monies. Homeowners will likely pay the higher retail cost for trees, although some communities may offer a program whereby the trees are purchased in a large contract volume, and these savings are passed on to the residents.

Previous state programs (i.e., the Shade Tree Program of the Department of Agriculture) have funded tree planting on public property. In the late-1970's and early-1980's communities participating in the program were eligible for up to 50 percent of their tree planting costs (maximum reimbursement of $50 per tree). In 1980, a total of 144,535 trees were planted at a cost of $4.9 million (average cost of $33.77 per tree). This was in addition to nearly $15 million of state and local monies spent on shade tree disease control.

After ten years of the tree planting program, 1.08 million trees will be planted. By age 40, each tree will sequester one half to three quarter ton of carbon (see Table 3.10). During this time, these trees will sequester in total between one half billion and one billion tons of carbon. Assuming similiar levels of emissions (see Table 3.3), this represents substantially less than one percent of the total emissions. Consequently, it is imperative that these trees be strategically planted to maximize their energy conservation potential.

3. *Shade Tree Availability*

Private nurseries will be the primary source of trees to meet the increased demand created by the tree planting program. Presently, there are some 280 commercial growers in Minnesota with approximately 4300 acres planted in nursery stock. About two-thirds of these growers are within the seven-county Metropolitan area. Outstate nurseries are mostly smaller and are scattered geographically throughout the state.

No actual numbers of shade trees produced in Minnesota is currently available. The nursery industry has been unable to estimate production due to the difficulty in obtaining this information from highly independent and geographically dispersed commercial growers. Nationally, the nursery industry has indicated that production levels can be increased to meet the demand for trees. As much of the planting stock used in Minnesota comes from outside the state, Minnesota tree planting goals as previously stated should be obtainable. However, certain desirable species may end up in short supply. Close monitoring of the planting program will be needed to insure that sufficient species diversity will be used as appropriate on a statewide basis.

4. *Community Involvement*

In order to accomplish any community tree planting goals for Minnesota several assumptions can be made:

(1) Public funds for tree planting (and especially tree maintenance) are limited;

(2) Tree planting without citizen involvement dooms many (if not most) trees to a premature death;

(3) Without public education regarding long-term care of trees, any tree planting efforts will not be successful;

(4) Local and state decision makers must be informed regarding the multiple benefits provided by urban and community forests and the necessity for funding even in comparison to other public priorities;

(5) Citizens personally involved with their community's trees will serve as models for stewardship of all natural resources.

The involvement of local community and neighborhood groups is critical to the expansion and improvement of tree planting and tree care programs. Numerous active community and neighborhood associations with strong volunteer networks are ready to assist these programs. These associations and organizations need to be identified within Minnesota and their involvement solicited for tree planting and tree care programs. Guidelines for community involvement, technical assistance and cost-share programs need to be developed at the state level to coordinate these efforts.

President Bush's national tree planting initiative entitled "America the Beautiful" proposes the following actions regarding community involvement:

(1) Inform community volunteer groups of the benefits of trees, tree planting, and tree care, and involve them in the planning stage for identifying and implementing local programs;

(2) Improve the effectiveness with which tree-care professionals in the public and private sectors work with and assist community groups to plant and maintain trees;

(3) Improve the effectiveness with which volunteer community groups can assist

their communities with tree planting and tree-care programs;

(4) Facilitate the exchange of information among various community groups and tree care professionals throughout the state;

(5) Provide local and state recognition to volunteer community groups and tree care professionals who excel in implementation of tree planting and care at the community level.

Strong state and local support of urban and community forestry programs will enable the state to compete more effectively for federal funding. Furthermore, the "America the Beautiful" initiative details specific state goals for community trees which for Minnesota include for FY 1991:

(1) to involve 133 local tree action groups in community tree planting (tree action groups are defined as non-profit and/or volunteer organizations committed to tree planting);

(2) to assist 350 communities in urban and community forestry programs;

(3) to plant, maintain or improve 75,800 community trees.

In working with a community, a multiple approach to tree planting and tree-care programs is suggested. This multiple approach emphasizes the energy conservation and carbon dioxide reduction benefits as well as other social, economic and environmental benefits of urban and community forests. Components of this approach are:

(1) to foster grassroots support and local initiative to gain legitimacy in the community and maintaining high visibility for the program;

(2) to focus on education (public, city officials, local business and the media) to gain a widespread acceptance of trees as well as the concept of urban and community forestry;

(3) to respond to local needs, such as jobs to provide an economic incentive to local businesses and the community;

(4) to develop creative funding potentials to reduce the cost of tax-supported programs.

In discussing the importance of urban and community forestry in community development, the Minnesota Shade Tree Advisory Committee (MSTAC) in its 1990 Report to the Legislature stated that "public acceptance of trees is not always automatic". In many community situations sociological rather than biological factors can have greater influence on the ultimate success of tree planting activities (Ames 1980). Therefore, broad-based citizen participation in community forestry planning and planting activities is necessary to stretch limited resources while insuring project success (Cole 1979).

An effective approach to promoting citizen participation in shade tree activities is the creation of neighborhood tree boards. Community participation in tree planting and tree care programs provides for benefits beyond the obvious objective of enhancing tree survival. The resulting sense of ownership not only increases the chance of project success but helps reduce the incidence of vandalism (especially when local youth are involved).

Furthermore, corporate participation in citizen tree planting activities should be solicited as it helps to define a sense of community in a larger context (Ames 1980). The trees planted with corporate support serve as living monuments to these contributors, but seldom are the contributions seen as self serving by the public.

5. *Youth Programs*

Tree planting activities represent an ideal opportunity for promoting youth development and teaching the value of volunteerism to youth while addressing community needs. For example, in 1990, a collaboration of the Minnesota based National Youth Leadership Council, Celebrate 1990, Minnesota Department of Education, Minnesota Forestry Association, and the Minnesota Arbor Month Committee planted one-million trees in Minnesota with much of this accomplished through local youth efforts. These efforts need to be continued and encouraged through various methods including the use of local school districts offering credit for youth service as a curricular option.

Non-profit programs such as the Twin Cities Tree Trust can be expanded in both the Twin Cities metropolitan area and outstate Minnesota to help achieve some of the tree planting goals. The Twin Cities Tree Trust is a model program which has demonstrated the positive role tree planting can serve by providing employment opportunities for youth. Through the Tree Trust, 15,000 disadvantaged youths have planted 400,000 small trees and transplanted 27,000 larger trees in Minnesota (Brown 1989). In addition, non-profit state sponsored youth employment programs such as the Minnesota Conservation Corps should be directed to include urban and community forestry activities within their mission and annual work goals.

E. Recommended Tree Planting Program for Rural Areas

A rural tree planting program would be most efficient to develop by combining and coordinating with existing federal and state programs. The piggy-backing of new funds with existing cost-share programs will increase the effective use of funds available for planting. Additional payments would increase interest in tree planting within such existing programs as the Agriculture Conservation Program, Conservation Reserve Program, Forest Incentives Program, Minnesota Forest Incentives Program, Stewardship Incentives Program and Soil and Water Conservation District cost-share programs. Funding should also be available to piggy-back with cost-share programs designed to encourage the planting of homestead and feedlot windbreaks.

Providing a $15 to 25 per acre annual payment to landowners could increase tree planting by 300,000 to 500,000 acres over a ten year contract period (Tom Kroll, Division of Forestry, personal communication). In agricultural areas, planting trees which reduce energy use by buildings would have high priority. This incentive could be paid as a piggy-back in the first years of the contract or added on at the end to extend the contract for an additional ten years. Up-front money would be more effective. Providing new markets such as wood-fueled power plants would also provide an incentive and could reduce the need for cash incentives in selected areas.

The cost for these additional planting incentives will average $5,000,000 per year over a 20-year life of the proposal. An additional cost is the need for an additional forester for each 4,000 acres planted. Help is also needed during the planting season and to shepherd the trees during their first few years. An additional 15 to 25 FTEs are required at a minimal cost of $525,000 per year.

Table 4.10. Tree planting cost estimates

Tree Size	Type	Amount	Information source	Comments
18-24" tall	seedling with Tubex	$10-$20	DNR estimate	tree shelter-high vulnerablity in public locations
5-6' sapling	container	$40	University of Minnesota	retail purchase; volunteer planting
1.5"-1.75" caliper	bare root	$51	Twin Cities Tree Trust	planted at one address
1.5"-1.75" caliper	bare root	$92	Twin Cities Tree Trust	containerized; planted at more than one location
2"-2.5" caliper	bare root B&B	$90 $120	City of Minneapolis	union contract labor; includes one year maintenance (watering, mulching)
2" caliper	B&B	$120	University of Minnesota	retail purchase; volunteer planting
3" caliper	B&B(44")	$160	Twin Cities Tree Trust	purchased bare root; planted in nursery; transplanted after 4 years; one address
2.5"-3" caliper	B&B(36")	$200	City of Robbinsdale	furnished and planted by private contractor
2" caliper	B&B(30")	$213	Twin Cities Tree Trust	wholesale purchase; one address
3.5" caliper	B&B(44")	$333	Twin Cities Tree Trust	wholesale purchase; one address

F. Further efforts required to improve understanding of energy conservation through tree planting

Conclusions that can be drawn about the potential utility of energy conservation plantings, are severely limited by the serious gaps in information available. Areas needing more conclusive and extensive data for energy conservation planting in Minnesota follow. * If 1991 LCMR funding is approved, work will begin on these tasks in July 1991.

1. *Verify Wind Shielding Effects of Vegetation in Urban Settings*
   - * a. Quantify the extent of existing tree cover in Minnesota communities.
   - * b. Develop capabilities to model the impact to vegetation on building air infiltration and energy use.
   - c. Develop wind tunnel and full scale experiments to predict wind shielding results.
   - d. Perform field monitoring of neighborhood and urban wind patterns and of energy savings to verify estimated savings.

2. *Quantify Heat Island Effects of Vegetation*

* a. Determine what areas (and subareas) of the state have urban heat island effects that may be influenced by planting programs. (Also see 1a above.)

* b. Develop capabilities to use the best known heat island simulation models.

c. Develop means of modelling micro- and meso-climatic impacts of vegetation on environments surrounding buildings (impacts of parking lots, ambient air temperature, etc.).

d. Collect data and make measurements of the effects of vegetation on heat islands.

3. *Develop Implementation Guidelines and Strategies*

* a. Model effects for a wider range of building types and environmental situations.

* b. Quantify more accurately the relationship between specific community planting programs and energy conservation.

* c. Determine effective strategies to gain professional and public understanding and use of energy conservation planting practices.

d. Develop means for reasonably and accurately quantifying other benefits and costs associated with tree planting, replacement, and preservation.

4. *Quantify Tree Characteristics Important in Energy Conservation*

a. Develop better methods of measuring and predicting tree canopy densities and their effect on building energy use.

b. Develop rapid and accurate means to estimate leaf area of trees and explore the relationships between leaf area and functional benefits of trees.

c. Develop better tree growth models which account for factors such as site conditions and irrigation and water use.

d. Evaluate the plant performance potential (tolerances, growth rates, mortality rates) of suitable species for each region of the state.

5. *Increase the Availability of "Solar Friendly" Trees*

a. Increase the availability of trees with beneficial forms and branch/foliation densities.

b. Develop ways to use tree propagation, tree selection and pruning techniques to increase utility of plants in energy conservation.

V. RECOMMENDATIONS FOR FUNDING A STATEWIDE TREE PLANTING PROGRAM

The report recommends an annual $13.5 million tree planting program for the state. The cost of the program should be borne by the primary fuel use sectors based on the percentage of CO_2 emissions contributed by each (see Figure 3.5). Based on 1988 emission levels of 24.4 million tons of carbon (89.5 million tons of CO_2) (see Table 3.3), this is equivalent to about 15 cents per ton of CO_2.

The proposed funding needed from each of the primary fuel use sectors to support the tree planting program is given in Table 4.11. The major portion of the funding will be obtained from the electric and transportation sectors. Options for obtaining funding from these sectors are discussed below.

Table 4.11. Funding required from each of the primary fuel use sectors to support the proposed tree planting program.

Sector	% Emissions	Cost (millions of $)
Electric	33.6	4.54
Transportation	31.8	4.29
Residential	12.0	1.62
Industrial	11.4	1.54
Commercial	8.1	1.10
Agriculture	3.0	0.41
Total		**13.5**

A. Electric Utility Sector

A surcharge on CO_2 emissions from the utility sector is recommended to support a tree planting program. The surcharge should be based on the percentage contribution to total CO_2 emissions by the electric utility companies (see Figure 3.5). Utilities are currently responsible for 33.6 percent of the releases of CO_2 to the atmosphere. Based on a surcharge of 15 cents per ton of CO_2, the contribution to the tree planting program from the electric utility sector is projected to be $4.54 million. The amount of the surcharge collected from each utility should reflect their contribution to total emissions of CO_2 from the electric utility sector.

The funds collected from the surcharge should be used to support tree planting programs within the service area of the utility. In lieu of payment of a portion of the surcharge, each utility should be allowed to provide a direct subsidy to the homeowner for tree planting (e.g. discount coupons for tree planting, direct billing discounts to homeowners, tree donations to homeowners). Based on the economic analysis in Section IV.B., the maximum rebate to the homeowner from the utility should not exceed $40 per tree.

The electric utilities in Minnesota need to be commended for their efforts in reducing emissions of CO_2. The utility companies have been actively developing and encouraging the use of energy conservation programs. Northern States Power, for example, projects that by 1995, peak electric demand will be reduced by 1000 megawatts through demand side management programs. Program expansions that continue to reduce CO_2 releases to the atmosphere will correspondingly reduce the amount of the surcharge assessed on the utility companies.

B. Transportation Sector

The members of the CO_2 Work Group recognized that some of the proposed options for obtaining funding from the transportation sector could require a constitutional change to implement. However, the group felt it was important to present all of the options discussed for consideration by the legislature.

1. *Taxation on Motor Fuel*

The current Minnesota excise tax on motor fuel is 20 cents per gallon. Current federal excise tax on motor fuel is 14.1 cents per gallon. The Minnesota excise tax on motor fuel generates approximately $440 million per year. State motor fuel excise taxes are constitutionally dedicated to the State Highway User Tax Distribution Fund (Article 14, Sections 5 & 10).

In order to use gas tax revenues for a tree planting program, or to enact an additional tax on motor fuel for such a program, a constitutional amendment changing Article 14, Sections 5 & 10 would have to be proposed by the legislature and approved by the public in a general election. Based on the consumption of 2.2 billion gallons of gasoline per year, the tax needed to support the transportation portion of the tree planting would be about 0.2 cents per gallon.

2. *Taxation of Motor Vehicles*

State motor vehicle registration fees generate approximately $255 million annually. Motor vehicle registration fees are constitutionally dedicated to the State Highway User Tax Distribution Fund (Article 14, Sections 5 & 9).

In order to use motor vehicle registration fee revenues for a tree planting program, a constitutional amendment changing Article 14, Sections 5 & 9 would have to be proposed by the legislature and approved by the public in a general election. At present, roughly four million vehicles are annually registered in the state. A one dollar increase in the motor vehicle registration fee would provide most of the funding needed from the Transportation sector to support the tree planting program.

3. *Tapping Federal Highway Funds*

Minnesota receives approximately $235 million annually in federal highway funds which are deposited into the State Trunk Highway Fund. This fund is used for construction and maintenance of the state trunk highway system. The federal funds available to states are generated primarily by federal gasoline taxes. The committee is unaware of any state or federal constitutional restrictions on the use of these funds. However, there may be federal statutory or regulatory restrictions on how states can use federal highway funds that would preclude their use for a tree planting program.

4. *Sales Tax on Automobiles*

The six percent sales tax on automobile sales generates approximately $180 to $220 million annually for the states general fund. Thirty-five percent of the Motor Vehicle Excise Tax (MVET) revenue is statutorily dedicated to the State Highway User Tax Distribution Fund. The other sixty-five percent is not constitutionally dedicated. Tapping MVET revenues to support the tree planting program is an option, but would require competing with all other general fund revenue recipients.

5. *Drivers License Fee:*

The state generates approximately $20 to $25 million annually in driver's license fees. The drivers license fee is an automobile user fee, much like vehicle registrations and gas taxes. The drivers license fees are deposited in the state trunk highway fund. There are no constitutional restrictions on the use of drivers license fees.

6. *Motor Vehicle Emission Testing Fee:*

The motor vehicle emission testing fee could be increased above the fee level needed to pay for the testing program. The increase in the fee could be used to support the tree planting program.

C. Residential, Commercial, Industrial and Agricultural Sectors

The residential, commercial, industrial and agricultural sectors combined are responsible for about 34 percent of total CO_2 releases to the atmosphere. Half of these releases are attributed to the use of natural gas (see Table 3.3). A surcharge of 15 cents per ton of CO_2 released from the burning of natural gas in these sectors would raise about $2.28 million for the tree planting program, or approximately half the total required from these sectors. An additional $2.4 million would be required from these sectors to provide the balance of the tree planting program.

Under this proposal, the natural gas companies would be allowed to provide direct subsidies to the homeowner for tree planting similar to those proposed for the electric utilities.

VI. INCENTIVES BEYOND THE TREE PLANTING PROGRAM FOR REDUCING EMISSIONS OF CO_2

The discussion on incentives to reduce CO_2 emissions was broadened beyond the development of a tree planting program. Most of this discussion occurred among representatives from the state departments on the CO_2 Work Group. Two of the issues the legislature should consider are given below:

1) The recently enacted federal Clean Air Act Amendments requires states to collect a fee of $25 per ton of emissions of regulated pollutants. Carbon dioxide is not included among the pollutants; however, Minnesota could decide to charge a fee on CO_2 emissions.

2) A fee on carbon emissions could have the effect of reducing CO_2 emissions. The most direct economic signal for reducing CO_2 emissions would be a fee levied on fossil fuel usage.

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