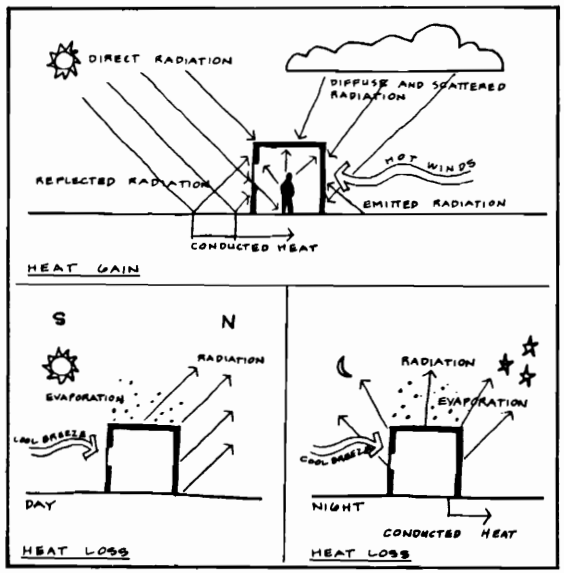
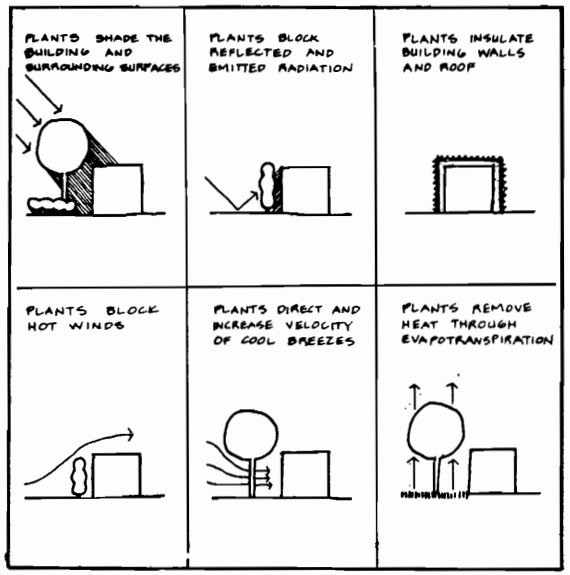
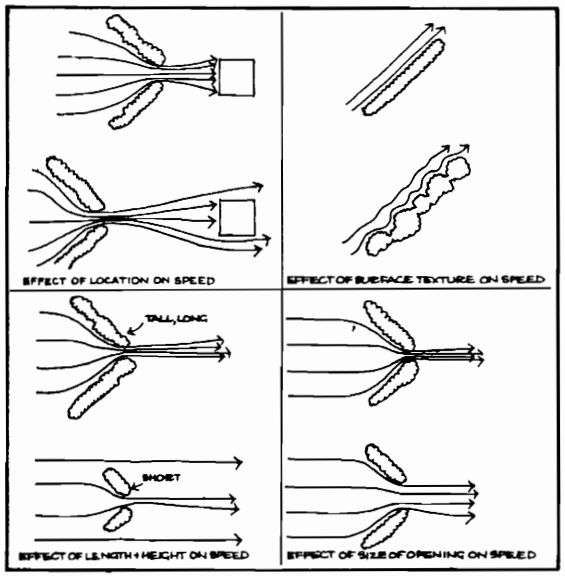
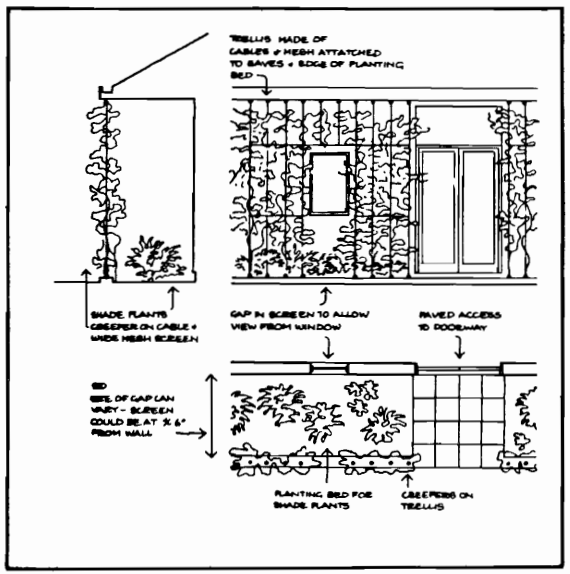
PLANTS FOR PASSIVE COOLING









DEPARTMENT OF LANDSCAPE ARCHITECTURE
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PLANTS FOR PASSIVE COOLING

A PRELIMINARY INVESTIGATION

OF THE USE OF PLANTS FOR PASSIVE

COOLING IN TEMPERATE HUMID CLIMATES

Anne Whiston Spirn, Assistant Professor of Landscape Architecture
Adèle Naudé Santos, Professor of Architecture and Urban Design

with

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Larry B. Harder, Research Assistant
Mark W. Rios, Research Assistant

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Anne Whiston Spirn was responsible for overall direction of the project. Adèle Naudé Santos collaborated on passive cooling design applications. David A. Johnson was responsible for the literature search and the section on plant materials and contributed valuable ideas and review on other sections. Larry B. Harder and Mark W. Rios worked on processes of energy transfer and passive cooling design objectives. Hugh Keegan participated in the initial stages of the project. Frederick E. Smith, Professor of Advanced Environmental Studies in Resources and Ecology, provided valuable review and advice. Drawings are by Adèle Naudé Santos, David A. Johnson, and Mark W. Rios.

Conrad V. Chester, Head of the Solar and Special Studies Section, Energy Division, Oak Ridge National Laboratory, initiated the project and contributed ideas and comments.

Report prepared by

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CONTENTS

INTRODUCTION

The Department of Landscape Architecture at Harvard University, under contract with the Oak Ridge National Laboratory, has studied the potential of vegetation for cooling small, detached residential and commercial structures. This project is part of the work supported by the Passive Cooling Program of the U.S. Department of Energy. The study was limited to temperate, humid climates; it does not address passive cooling in hot, humid or hot, arid climates. This report documents the results of that research, including a critical review of the literature, a brief review of energy transfer processes, a checklist of design objectives for passive cooling, a demonstration of design applications, and a palette of selected plant species suitable for passive cooling.

The major research questions were:

— How can vegetation be used to cool small residential and commercial structures, and what is the energy-saving potential of such techniques?

— What is the state-of-the-art, and what untried techniques have high potential?

— How will the use of vegetation for passive cooling affect the form, structural support system, maintenance, and appearance of a building?

— How can a design using vegetation for passive cooling be staged to be of immediate, as well as long-term, benefit?

In response to these questions, the following research plan was pursued:

— Review the existing literature;

— Identify a range of design strategies for reducing the surface and interior temperature of the building through the use of vegetation;

— Demonstrate the application of passive cooling design strategies to building and landscape design elements;

— Identify key building and site design issues associated with these design strategies such as maintenance, structural requirements, timing, suitable plant types, and aesthetics;

— Identify a palette of selected plant species which are suitable for passive cooling in the temperate, eastern United States.

A major objective of the literature review was to determine the extent of quantitative data on the reduction of building temperature and energy consumption by vegetation and to determine the general applicability of these findings. Although there is little quantitative data on the ability of plants to accomplish passive cooling, that data which does exist is extremely promising. A systematic exploitation of landscaping around and on buildings can yield substantial savings in energy consumption and in the shift of energy demands to off-peak hours. With a few notable exceptions, vegetation is

currently used mainly to provide shade from direct solar radiation, and its full potential for passive cooling is seldom realized. Applied systematically, plants may eliminate the need for air-conditioning in the relatively cool Northeast. In the warmer Southeast, plants may reduce the amount of air-conditioning required and shift the energy demand to off-peak hours. Plants should be employed to manipulate the entire radiation environment, to control air movement, and to achieve maximum heat loss through evaporation. Plant species should be carefully selected with regard to their physiology and their appropriateness for specific cooling functions and location.

Plants are only one element of the landscape which may be exploited for passive cooling. The judicious siting of buildings with respect to waterbodies, landforms, and existing forests can enhance passive cooling. Planting design should also be integrated with overall building form to achieve maximum cooling. These issues, however, are beyond the scope of this preliminary study.

LITERATURE REVIEW

The use of plants for passive cooling affords an opportunity to eliminate or reduce air-conditioning in small structures. Widespread application of this technique is currently hampered by a fragmented literature and by confusing, sometimes conflicting, findings. There is presently no overview of the subject and no review of the literature and current practice. This report provides an introduction to the literature and discusses the use of plants for passive cooling in temperate, humid climates.

The literature was surveyed to:

— Identify the state-of-the-art in the use of vegetation for passive cooling, especially as applied to temperate, humid regions;

— Identify techniques that are currently being implemented;

— Identify untried techniques with high potential;

— Determine the extent of quantitative data on reduction of temperature and energy consumption due to passive cooling by vegetation;

— Identify areas for future research.

The literature relating to vegetation and passive cooling occurs in diverse categories and sources. Seven categories were defined in the course of the literature review:

1) Modification of Microclimate by Vegetation

2) Modification of Microclimate by Urbanization

3) Climate and Architecture

4) Passive Cooling: Processes and General Applications

5) Passive Cooling and Architecture

6) Passive Cooling and Vegetation

7) Architecture and the Use of Vegetation on Buildings

The first two and the fourth categories consist primarily of monographs and articles by climatologists and foresters. The third and seventh categories are mainly written by and for architects and landscape architects. The fifth and sixth categories are interdisciplinary. They consist of articles and conference papers by climatologists, foresters, architects, landscape architects, and engineers.

The literature of the past three decades falls into two major periods: the 1950's and the 1970's. Collaboration among landscape architects, architects, climatologists, and engineers produced a large body of literature on the integration of plants, architecture, and climate in the 1950's. Deering (1953) outlined the processes by which plants accomplish passive cooling. Olgyay (1963) and Aronin (1953) provided an introduction to climate and architecture;

Olgyay and Olgyay (1957) summarized the shading effect of trees. White (1954) and Evans (1957) showed how vegetation outside a building can be manipulated to increase ventilation within the building and to direct airflow around it. From 1949 to 1951, House Beautiful magazine published a series of articles on "The Climate-Controlled House" which demonstrated how plants, among other design elements, could be used to accomplish passive cooling and heating in different climates. These studies have served as major sources for nearly three decades. Most architectural monographs and articles still rely primarily on these early works and do not incorporate more recent research (Robinette, 1972 and 1977).

The literature of the 1970's is growing, but is fragmented and often conflicting. The literature of the design professions is largely derivative. The climatological literature is mainly concerned with metropolitan-scale phenomena which are difficult to relate to a more local situation (World Meteorological Association, 1970). When climatologists do focus on the role of plants in the formation of urban microclimate, they refute several assumptions commonly held by architects and landscape architects. Heisler and Herrington (1976) dispel the belief that trees lower air temperatures in the city. They maintain that an alteration in air temperature occurs only when a forest-like environment is created, as in large parks, but that individuals or small groups of trees have a negligible effect. The air temperature at ground level under a tree may be 20 F less than the temperatures at ground level over an asphalt parking lot in direct sun, but this difference is rapidly diffused by air movement. Although trees may not lower air temperatures around a building, vegetation can substantially decrease both the direct solar and the infrared radiation to which a building is subjected. The role of vegetation in controlling solar and thermal radiation is of primary importance.

Some research belies the common perception that deciduous trees block radiation in summer and permit penetration of substantial radiation in winter. In fact, deciduous trees vary widely in the amount of radiation they allow to penetrate in winter. The density of twigs and branches determines how much radiation is reflected, diffused, or absorbed by a leafless tree. Some deciduous trees block more than 50% of direct solar radiation in winter. Preliminary research indicates that certain deciduous species, like the sycamore, may block nearly as much radiation in winter as in summer (Johnson et al., 1980). Tree species should be selected which provide maximum summer shade, and which block the least winter sun. More research in this area is needed.

Most references use broad categories of size (tree, shrub, or groundcover) and geometry (columnar, spherical, conical) to recommend appropriate plants for passive cooling (Robinette, 1972; Heisler and Herrington, 1976). Lesiuk (1978) urges the use of a more precise selection system tailored to the character of a specific situation and based on the interaction of heat transfer processes and plant morphology. Lesiuk, drawing from the biological literature, demonstrates that the shade provided by plants is a function of the angle of inclination of leaves, their distribution on the plant, the number of leaf layers through which radiation must pass, and the geometry of the stand. The amount of energy dissipated through

evapo-transpiration also varies from species to species. Transpiration is a function of plant morphology (e.g., total leaf area, size and spacing of stomata) as well as environmental factors (e.g., water availability, solar radiation). Energy dissipated through convection varies with shape and size: lobed leaves are more efficient in dissipating energy than entire leaves; small, narrow leaves are more efficient than large, broad leaves (Lesiuk, 1978).

There is little quantitative data on the ability of plants to accomplish passive cooling of small structures, but that data which does exist is extremely promising. Deering (1956) observed a 20F difference in maximum temperatures between the interior of a house trailer in dense shade and in full sun. In shade, the interior temperature remained over 75F for only 5 hours as compared to 11.5 hours in full sun. Landsberg (1970) documented the formation of a heat island after sunset in a small, paved courtyard within an isolated, five-story building complex surrounded by lawn and trees. The air temperature in the courtyard was 0.9F above that over the lawn. This effect was caused by the nightly release of heat absorbed in the pavement and masonry during the day.

Parker (1979) measured a 35% reduction in energy used for air conditioning of a mobile home in Miami, Florida, only one year after the installation of plants strategically placed to provide passive cooling. Parker designed the landscaping to reduce heat gain by direct sunlight, by reflected and emitted radiation from surrounding surfaces, by convection and conduction, and to increase heat loss by convection and evaporation. This is an unusual case. Vegetation is currently used mainly for aesthetics and to provide shade from direct solar radiation. Its full potential for passive cooling is seldom realized.

Several areas hold great promise for future research. The reduction of thermal radiation from surrounding surfaces and the significance of cooling through evapotranspiration are two important areas for future research. Further research relating plant morphology to passive cooling for specific situations is also likely to be rewarding.

This study is a preliminary investigation. A more comprehensive exploration of passive cooling techniques as applied to a range of building and landscape types and of strategies such as shifting energy demands to off-peak hours is needed. Such a study would advance the current state-of-the-art by permitting and promoting a systematic implementation of passive cooling strategies and techniques.

PROCESSES OF ENERGY TRANSFER

Buildings gain and lose heat through four major processes of energy transfer: radiation, conduction, convection, and evaporation. Heat gain and loss occur within three zones: the building interior, the exterior walls and roof, and the environment surrounding the building. Radiant energy, for example, is transmitted to the building interior through transparent openings in the building shell (e.g., windows, skylights). In addition, some of the radiant energy which strikes exterior walls and roof is absorbed and gradually conducted to the interior. Radiant energy is also absorbed by the surrounding environment and the stored heat is transferred to the building by radiation, conduction, or convection.

The following pages provide a brief review of the processes by which buildings gain or lose heat. Radiation is the primary source of heat gain. Direct and indirect solar radiation are the most important sources, but reflected solar radiation and thermal radiation emitted from terrestrial surfaces are also very significant. Evaporation and convection are the major processes by which heat loss may be accomplished. Radiation by building walls and roof to heat sinks (e.g., clear night sky) can also provide significant heat loss. A comprehensive design for passive cooling should exploit all four processes of energy transfer to prevent heat gain and encourage heat loss in all three building zones.

PROCESSES OF ENERGY TRANSFER

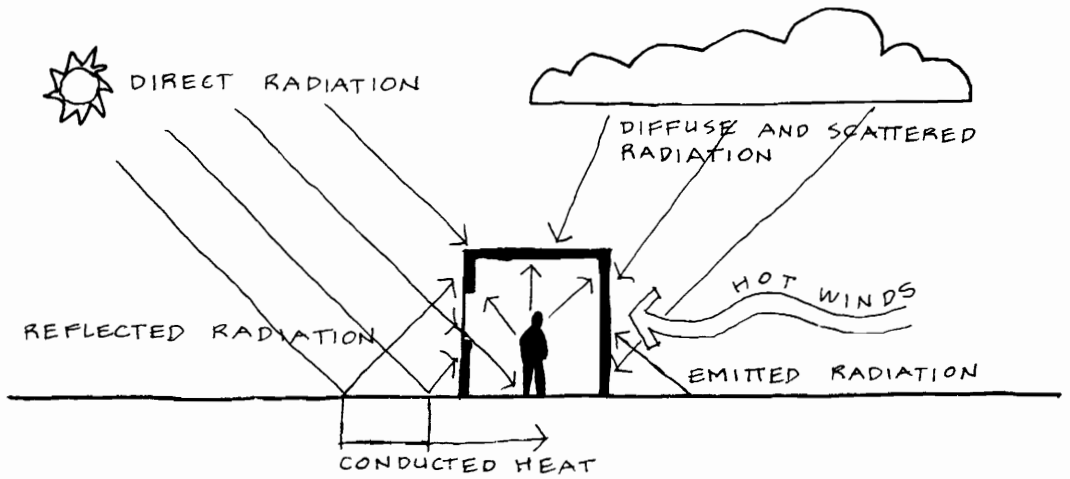
HOW BUILDINGS GAIN AND LOSE HEAT

HEAT GAIN

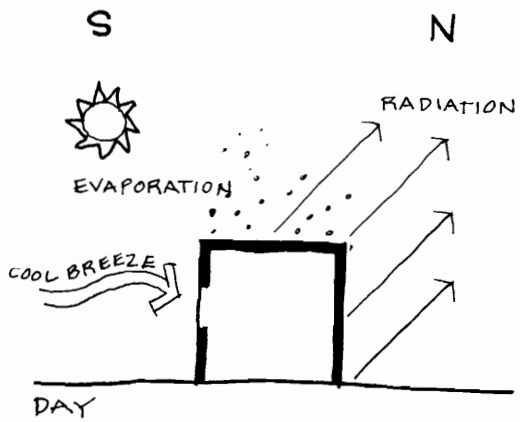
- Direct Radiation
- Indirect Radiation (diffuse and scattered radiation, back radiation from the sky).
- Reflected Radiation.
- Emitted Radiation.
- Convection.
- Conduction.
- Generation of heat in building interior.

HEAT LOSS

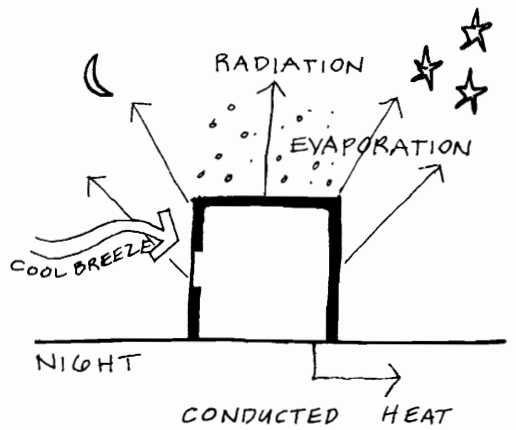
- Radiation.
- Convection.
- Evaporation.
- Conduction.



HEAT GAIN



HEAT LOSS

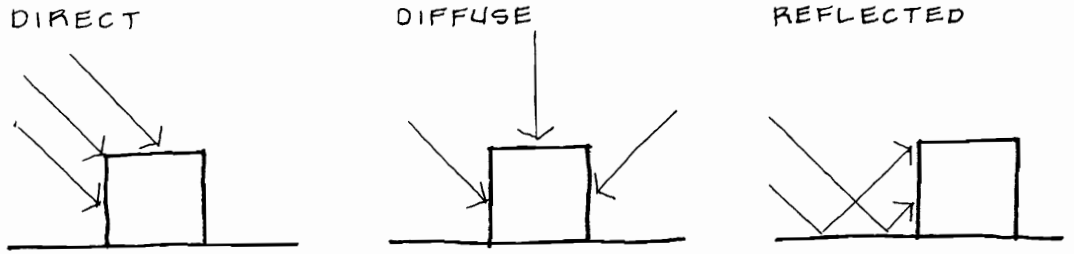


HEAT LOSS

PROCESSES OF ENERGY TRANSFER

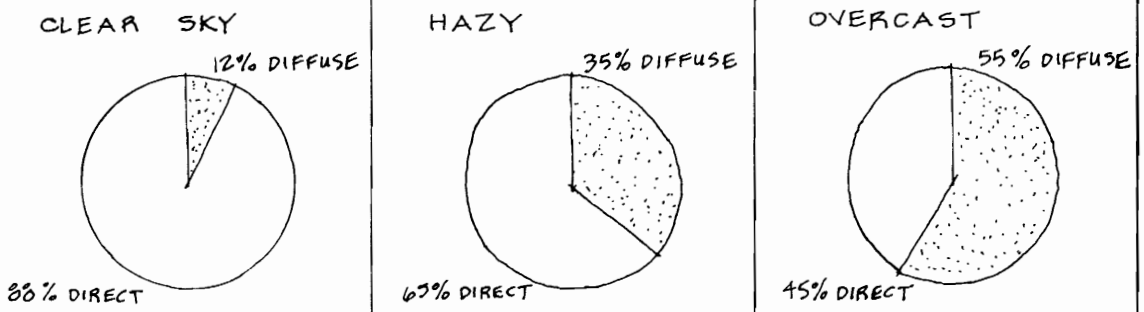
COMPONENTS OF TOTAL SOLAR RADIATION

Incident solar radiation may be direct, diffuse, or reflected.



COMPONENTS OF INCIDENT RADIATION

The proportion of direct versus diffuse radiation varies with atmospheric clarity (a function of cloud cover, humidity, and particulates) and with sun altitude.



PROPORTIONS OF DIRECT VS. DIFFUSE RADIATION

Source: Givoni, Man, Climate and Architecture, 1976.

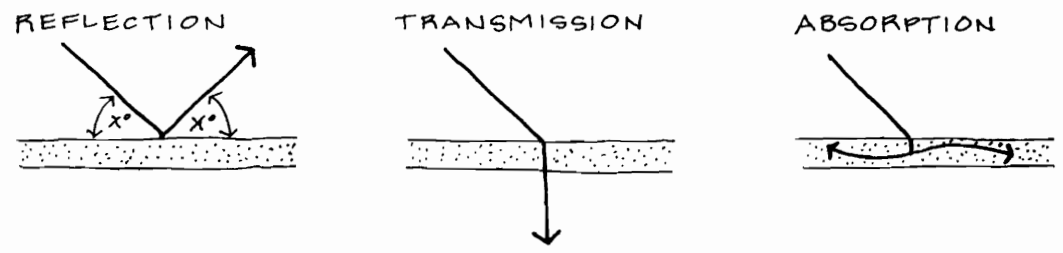
PROCESSES OF ENERGY TRANSFER

INCIDENT RADIATION

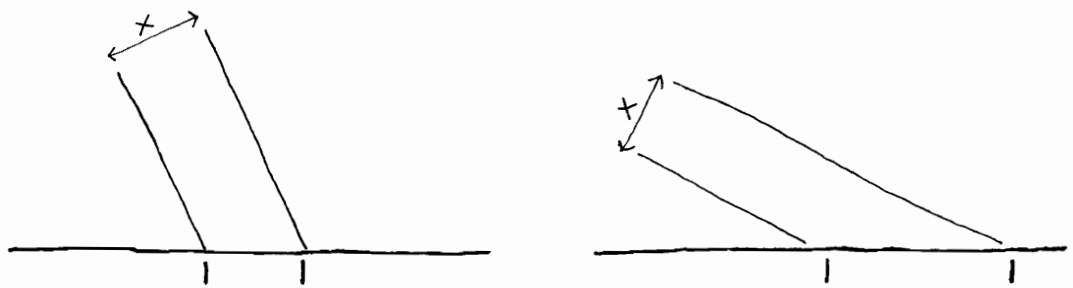
All radiation that is incident on any substance--solid, gaseous, or liquid--must either be reflected, transmitted, or absorbed.

The intensity of incident radiation varies with the angle at which radiation strikes the surface. The more perpendicular the angle of incidence, the greater the intensity. The angle of incidence is a function of solar angle and the angle of the incident surface.

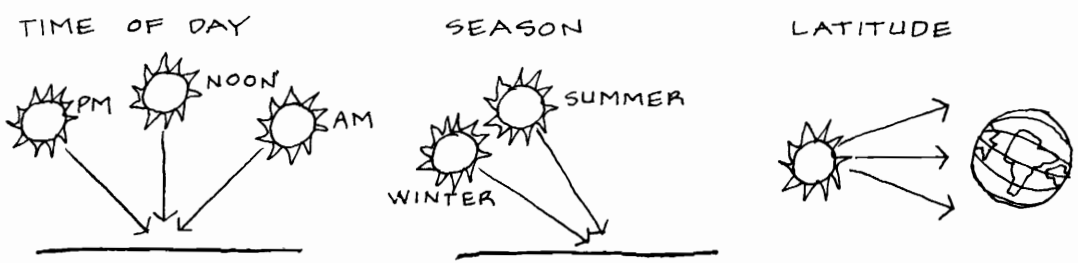
The solar angle varies with time of day, season of year, and latitude.



FATE OF INCIDENT RADIATION



ANGLE OF INCIDENCE AND INTENSITY OF RADIATION



FACTORS AFFECTING SOLAR ANGLE

PROCESSES OF ENERGY TRANSFER

REFLECTION AND ABSORPTION

Radiation impinging on an opaque surface is reflected or absorbed.

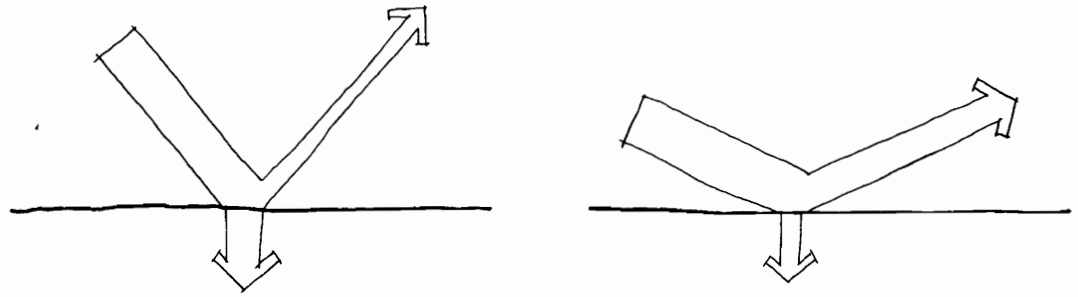
The amount of radiation reflected by a substance is a function of:

- The angle of incidence

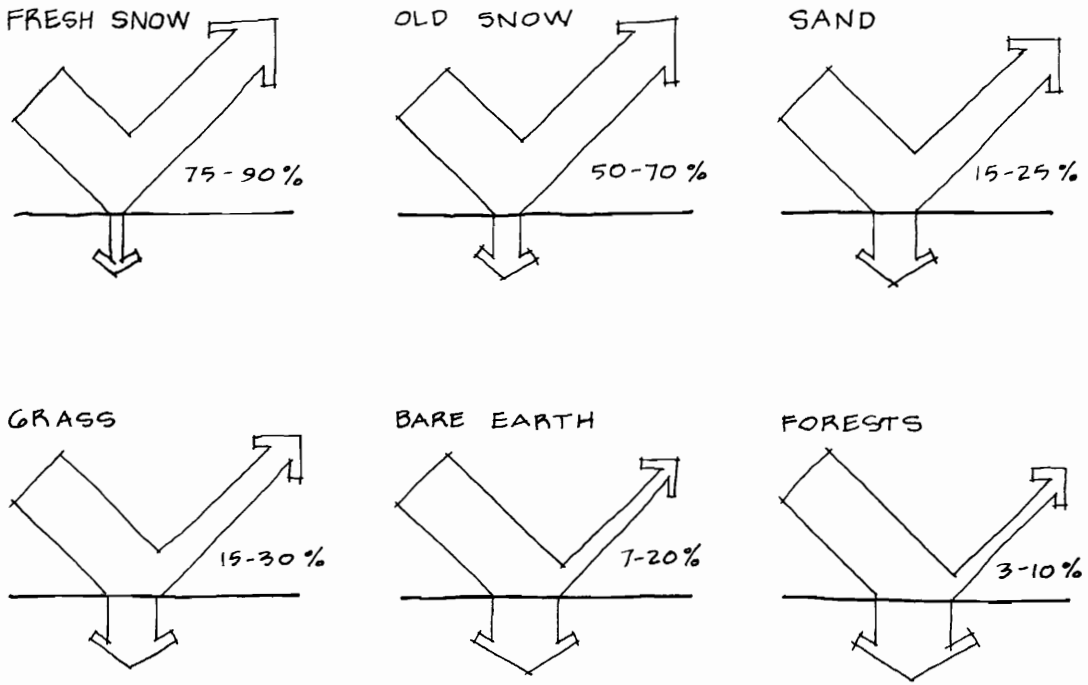
- Reflectivity of the surface

Absorbed energy is eventually reradiated or emitted, unless consumed in a process such as evaporation.

Source: Trewartha (1968).



ANGLE OF INCIDENCE AND REFLECTION

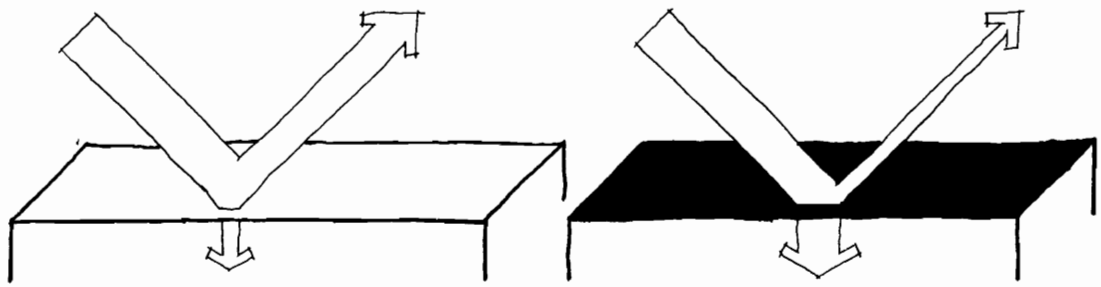


SURFACE REFLECTIVITY OF TERRAIN (ALBEDO)

PROCESSES OF ENERGY TRANSFER

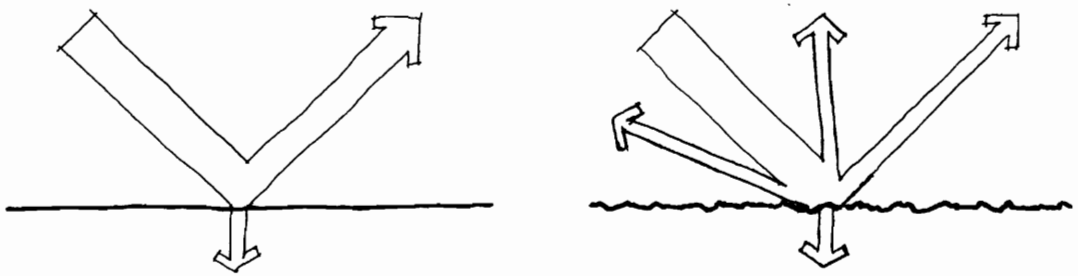
REFLECTION AND ABSORPTION

Dark-colored surfaces absorb more and reflect less radiation than light-colored surfaces.



SURFACE COLOR AND ABSORPTION

Rough surfaces reflect diffusely in all directions.



SURFACE TEXTURE AND REFLECTION

PROCESSES OF ENERGY TRANSFER

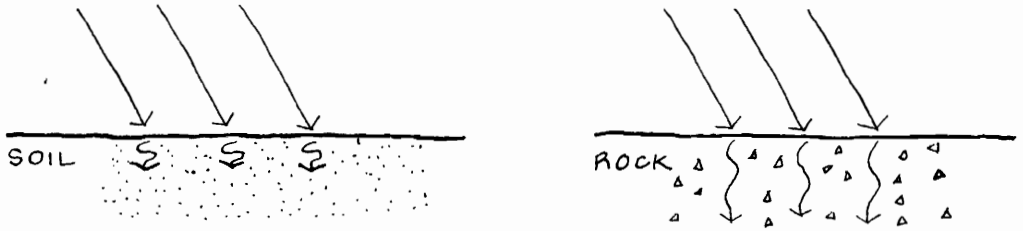
CONDUCTION: FACTORS AFFECTING AMOUNT AND RATE OF HEAT TRANSFER

The amount and rate of heat conducted depends upon a substance's:

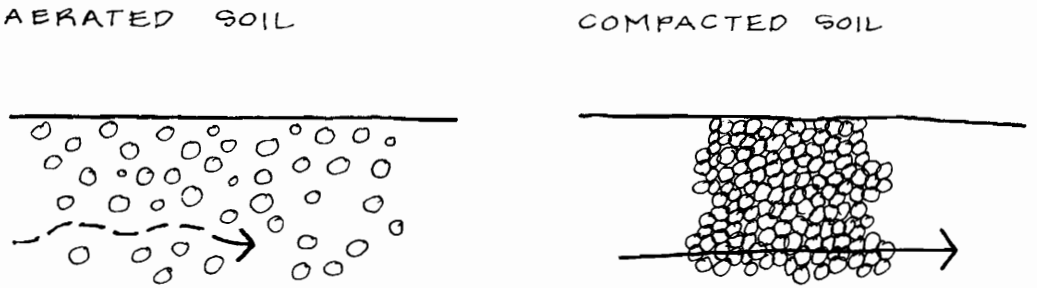
- conductivity
- homogeneity

Cooling occurs when heat is removed from the source and transferred by molecular conduction to another location.

Insulation retards the transfer of heat by conduction. Insulation can be accomplished by interposing a substance of low conductivity between the source of heat and cooler zones.



THERMAL CONDUCTIVITY AND RATE OF HEAT TRANSFER



THERMAL CONDUCTIVITY, HOMOGENEITY, AND HEAT TRANSFER

EFFECT OF INSULATION

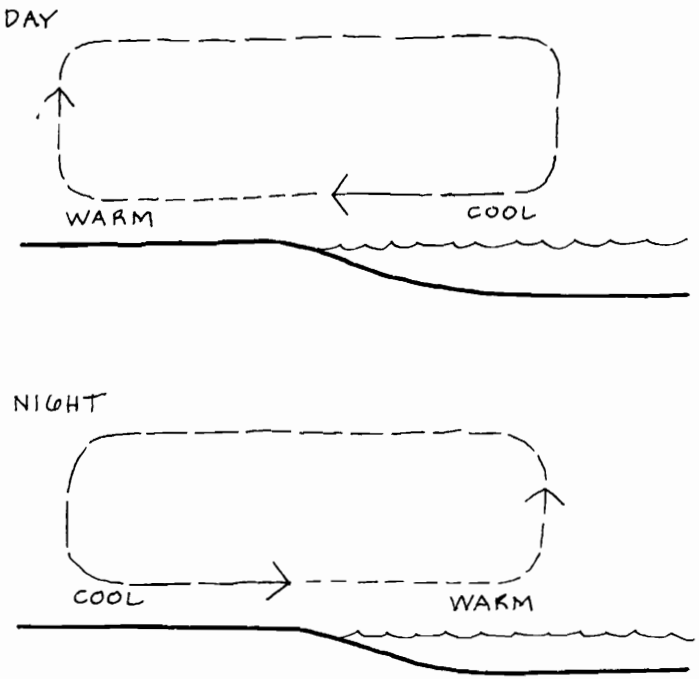
PROCESSES OF ENERGY TRANSFER

CONVECTION

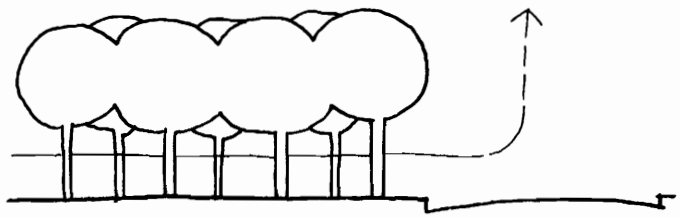
Convection is the transfer of energy by the movement of heated portions of a fluid or gas. Convection involves physical movement, unlike conduction which takes place in a stationary system.

Convective cooling occurs by the transfer of heated material to another location and its replacement by cooler material.

Different land and water surfaces absorb different amounts of heat, and heat or cool the air immediately above to differing degrees. Warm air rises and is replaced by cooler air, causing local winds and breezes.



LAND AND SEA BREEZE



THERMAL AIR MOVEMENT

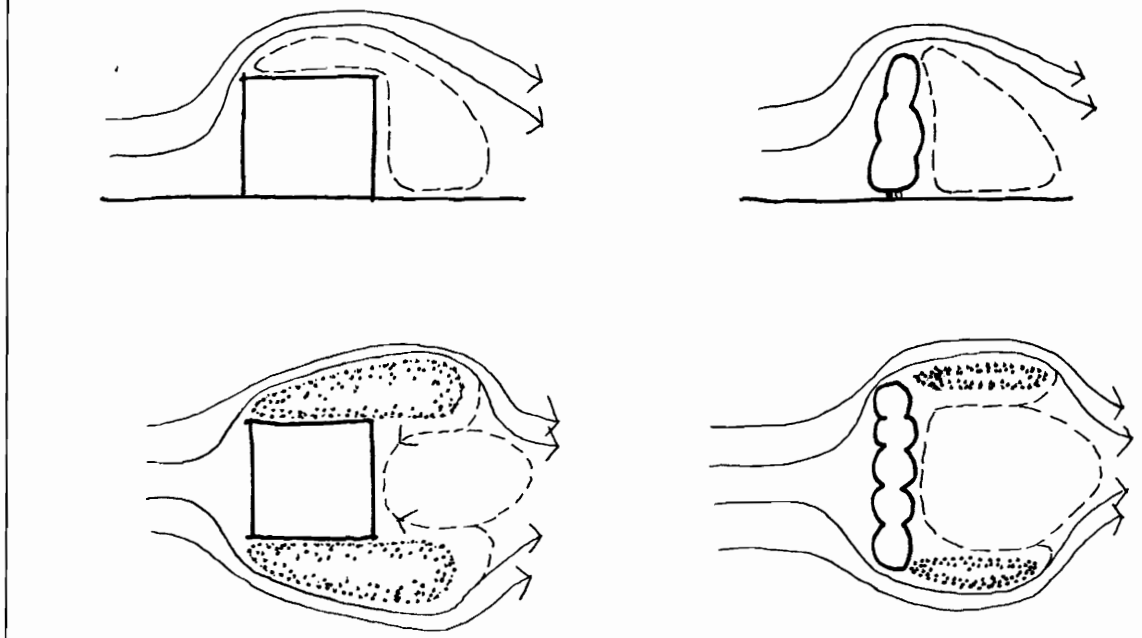
PROCESSES OF ENERGY TRANSFER

CONVECTION: MODIFICATION OF WIND BY OBSTACLES

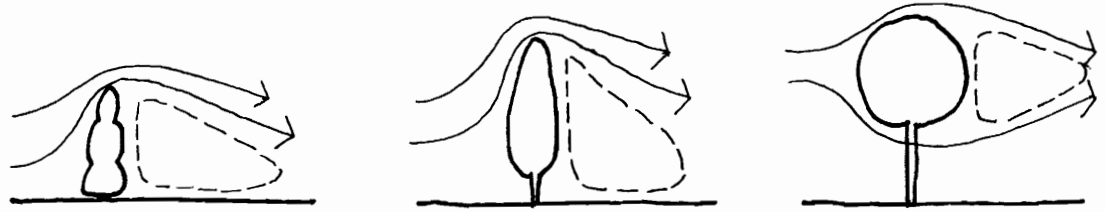
The direction and speed of wind are altered as it moves around an obstacle. Variables determining these alterations are the obstacle's:

- density
- surface texture
- height
- width
- length
- shape
- profile
- orientation
- size of openings

Sources: Gandemer and Guyot (1976), Shellard (1965), White (1954).



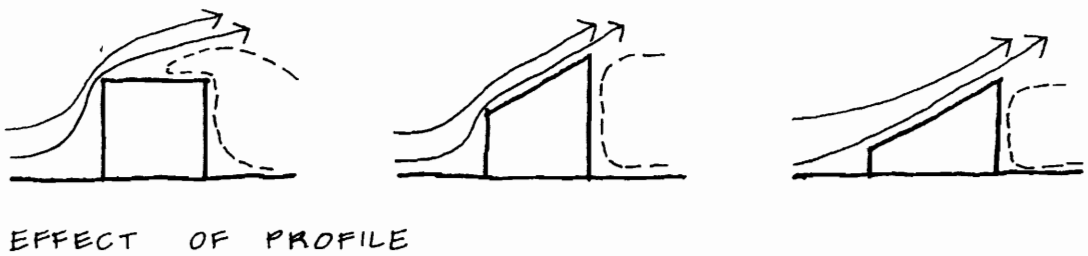
EFFECT OF HEIGHT & WIDTH



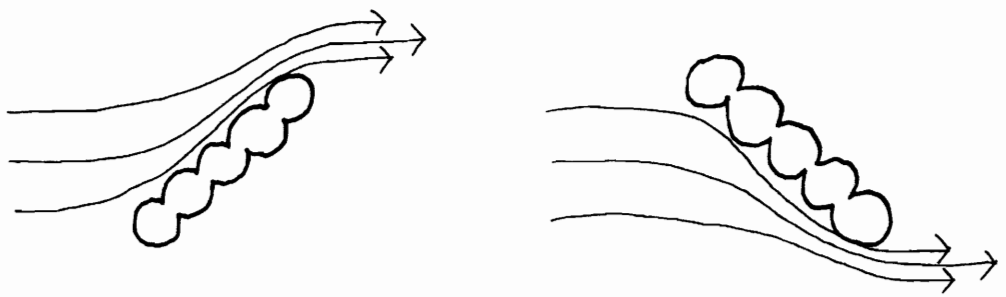
EFFECT OF DENSITY

PROCESSES OF ENERGY TRANSFER

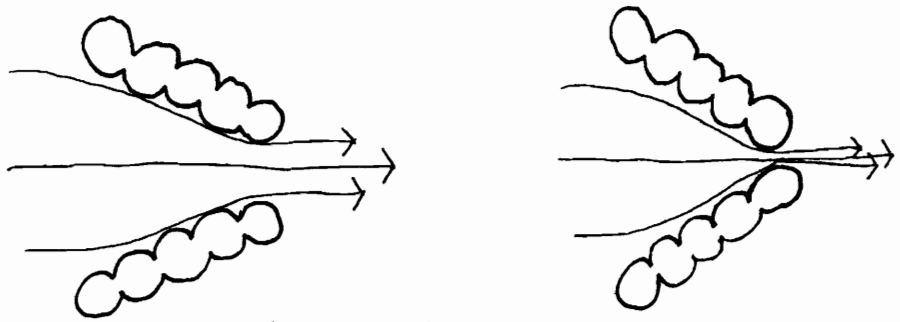
CONVECTION: MODIFICATION OF WIND BY OBSTACLES



EFFECT OF PROFILE



EFFECT OF ORIENTATION



EFFECT OF SIZE OF OPENING

Source: Evans (1957).

PROCESSES OF ENERGY TRANSFER

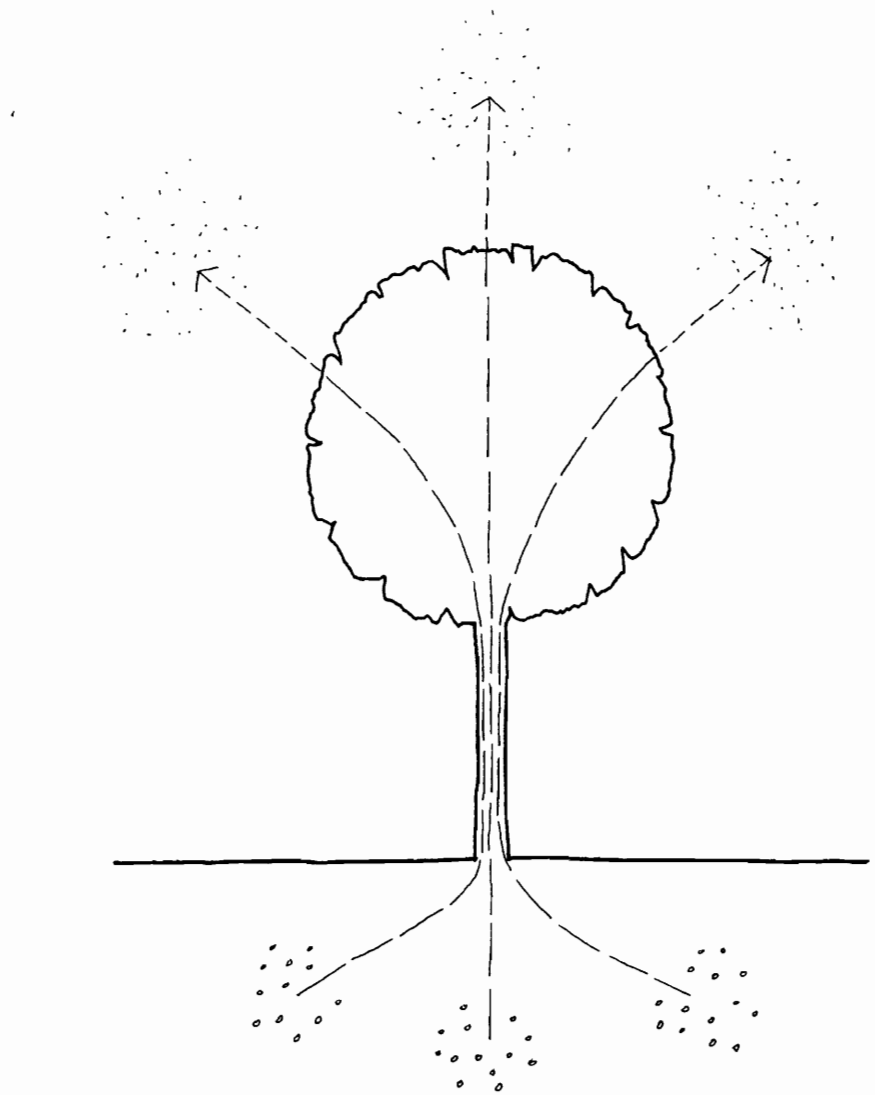
EVAPORATION

Evaporation is the transformation of a liquid to a gas. Considerable energy, in the form of heat, is required to accomplish the transformation. In the process, heat is added without raising the temperature. Thus evaporation has a cooling effect.

The rate of evaporation depends upon:

- water available at the surface
- the degree to which that surface is heated
- the humidity of the overlying air
- air motion

Roughly half of the energy absorbed by a tree is used for evapotranspiration. Most of the rest is lost by radiation and convection. Only a very small amount is stored in the plant.



PASSIVE COOLING DESIGN OBJECTIVES

To realize its full potential, a design for passive cooling must prevent heat gain and encourage heat loss both within the interior and exterior of the building itself and in the surrounding environment. The following pages summarize the ways that plants accomplish passive cooling. Design objectives are organized by energy transfer processes:

1) Prevent Heat Gain Through Radiation

2) Encourage Heat Loss Through Radiation

3) Prevent Heat Gain Through Convection

4) Encourage Heat Loss Through Convection

5) Encourage Heat Loss Through Evaporation

6) Prevent Heat Gain Through Conduction

7) Encourage Heat Loss Through Conduction

The checklist of design objectives should be used to promote the employment of the maximum passive cooling strategies. Not all the design objectives are equally important. Blocking direct solar radiation and encouraging ventilation and evaporation are the most widely recognized and the most significant. Less recognized, but equally important is the need to block radiation reflected and emitted by surrounding surfaces. The promotion of radiant heat loss to heat sinks, such as the clear night sky, is an underutilized, though less important, strategy. This, contrary to other techniques, implies the lack of plants (which would inhibit radiant heat loss). Preventing the infiltration of hot winds may be significant in hot climates where air conditioning is used extensively. The promotion of evaporative cooling should be used with caution in very humid climates where an increase in humidity may increase discomfort. The use of plants to accomplish passive cooling through conduction has much less potential than the other three processes.

Many of the design objectives are complementary; others conflict. A single row of trees, strategically positioned, can both block direct and reflected radiation from building walls and funnel breezes into the building. A solid cover of vines on building walls and roof, however, blocks direct, diffuse, and reflected radiation, but also inhibits heat loss by radiation to the night sky. Complementary objectives must be integrated, and the relative importance of conflicting objectives must be weighed and resolved for every specific situation.

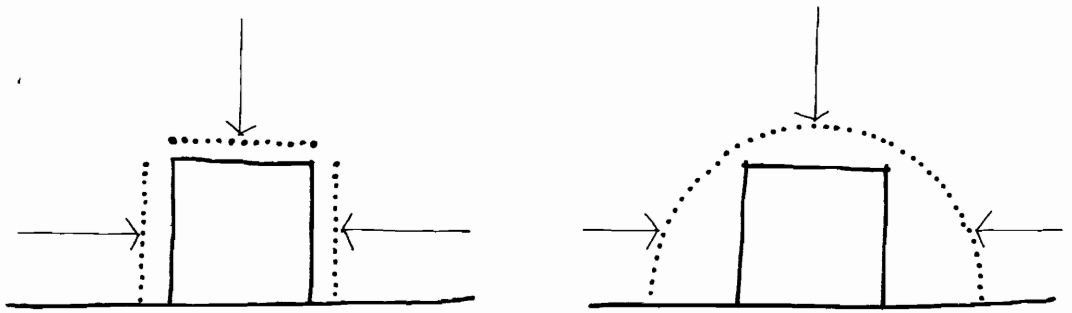
Any design for passive cooling should apply more than one design objective. The next section of the report, "Passive Cooling Design Applications," demonstrates the integration of many objectives within the design of one building or landscape element. These applications are cross-referenced with design objectives in the following pages.

PASSIVE COOLING DESIGN OBJECTIVES

GOALS

Prevent Heat Gain

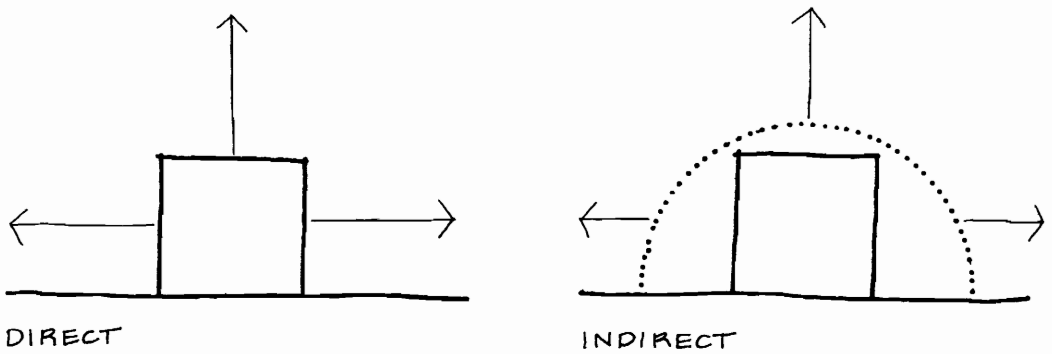
- Direct (within building and on building walls and roof)
- Indirect (in surrounding exterior environment)



PREVENT HEAT GAIN

Encourage Heat Loss

- Direct (from building interior, walls, and roof)
- Indirect (from exterior environment)



ENCOURAGE HEAT LOSS

PASSIVE COOLING DESIGN OBJECTIVES

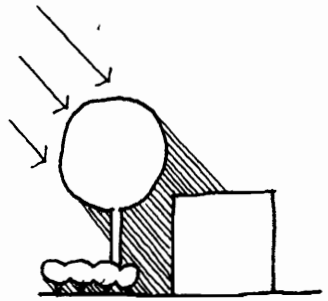
HOW PLANTS ACCOMPLISH COOLING

Plants prevent heat gain by:

1. Shading the building and surrounding surfaces.
2. Blocking radiation reflected or radiated from surrounding surfaces.
3. Insulating building walls and roof.
4. Blocking hot winds.

Plants enhance heat loss by:

5. Directing and increasing velocity of cool breezes.
6. Removing heat from the surrounding environment through evapotranspiration.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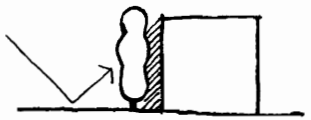
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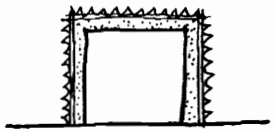
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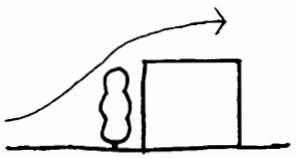
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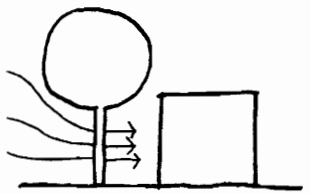
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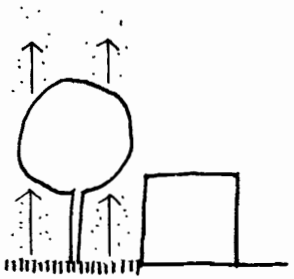

6

PASSIVE COOLING DESIGN OBJECTIVES

1. AVOID HEAT GAIN THROUGH RADIATION

1A. Avoid direct solar radiation.

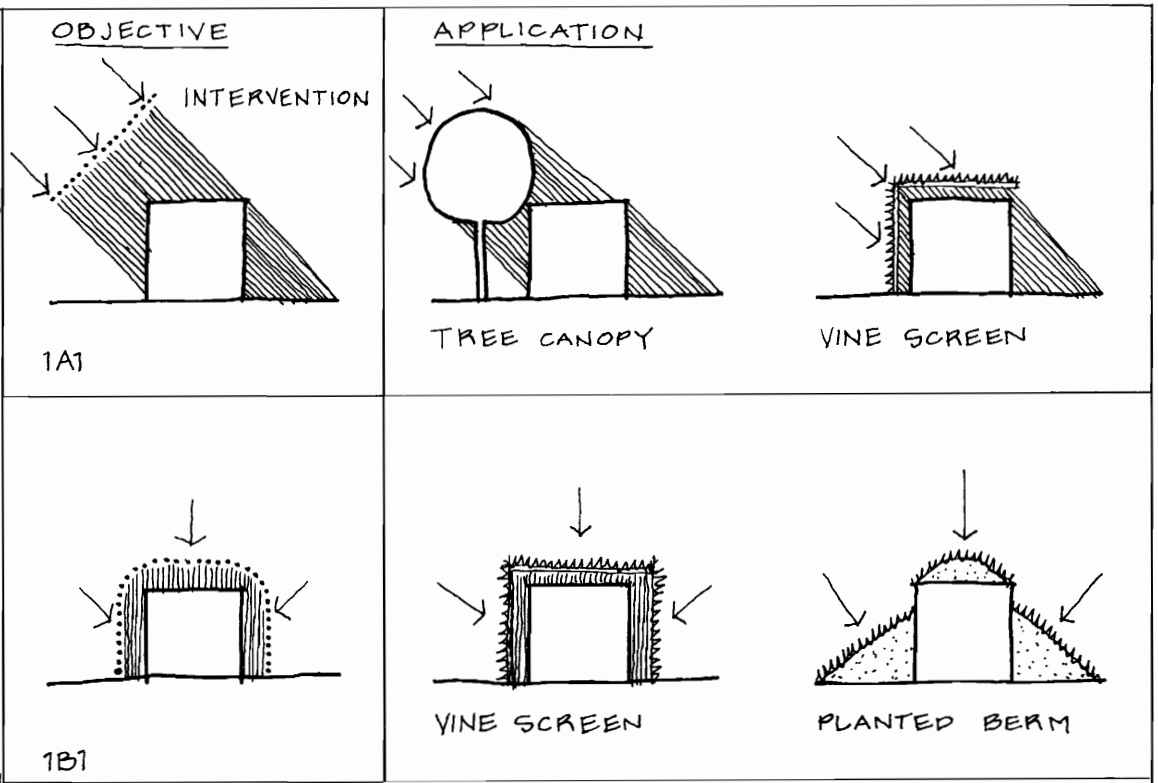
1A1. Block incident radiation.

Applications: Tree/shrub Wall, Planted Berm Wall, Peat Moss Wall, Planter Wall, Stepped Wall, Stepped Planters, Window Planters, Window Planter Wall, Tree Screen, Balcony Edge, Brise Soleil Planters, Freestanding Lattice, Freestanding Planter Screen, Vine-Covered Wall, Vine-Covered Lattice, Vine-Covered Cables, Detached Lattice, Sliding Wall Planter, Sliding Window Planter, Hinged Planter Screen, Pivoting Screen/ Trellis, Roof Lattice, Turf Roof, Roof Garden, Trellised Roof Garden, Glazed Planter Roof, Tree Canopy, Freestanding Trellis, Attached Trellis, Fixed Wind Shade, Shade Court/ Sun Pocket.

1B. Avoid indirect solar radiation (diffuse and scattered radiation from sky).

1B1. Block incident radiation from sky.

Applications: See 1A1.



PASSIVE COOLING DESIGN OBJECTIVES

1. AVOID HEAT GAIN THROUGH RADIATION (continued)

1C. Avoid reflected radiation.

1C1. Block radiation reflected by adjacent ground and walls.

Applications: See 1A1.

1C2. Reduce radiation reflected by surrounding ground and walls.

Applications: Tree/Shrub Wall, Planted Berm Wall, Tree Screen, Freestanding Lattice, Freestanding Planter Screen, Vine-Covered Cables, Sliding Wall Planter, Hinged Planter Screen, Pivoting Screen/Trellis, Tree Canopy, Freestanding Trellis, Attached Trellis, Plant Floor, Unit Pavers in Grass, Grass Pavement, Shade Court/Sun Pocket.

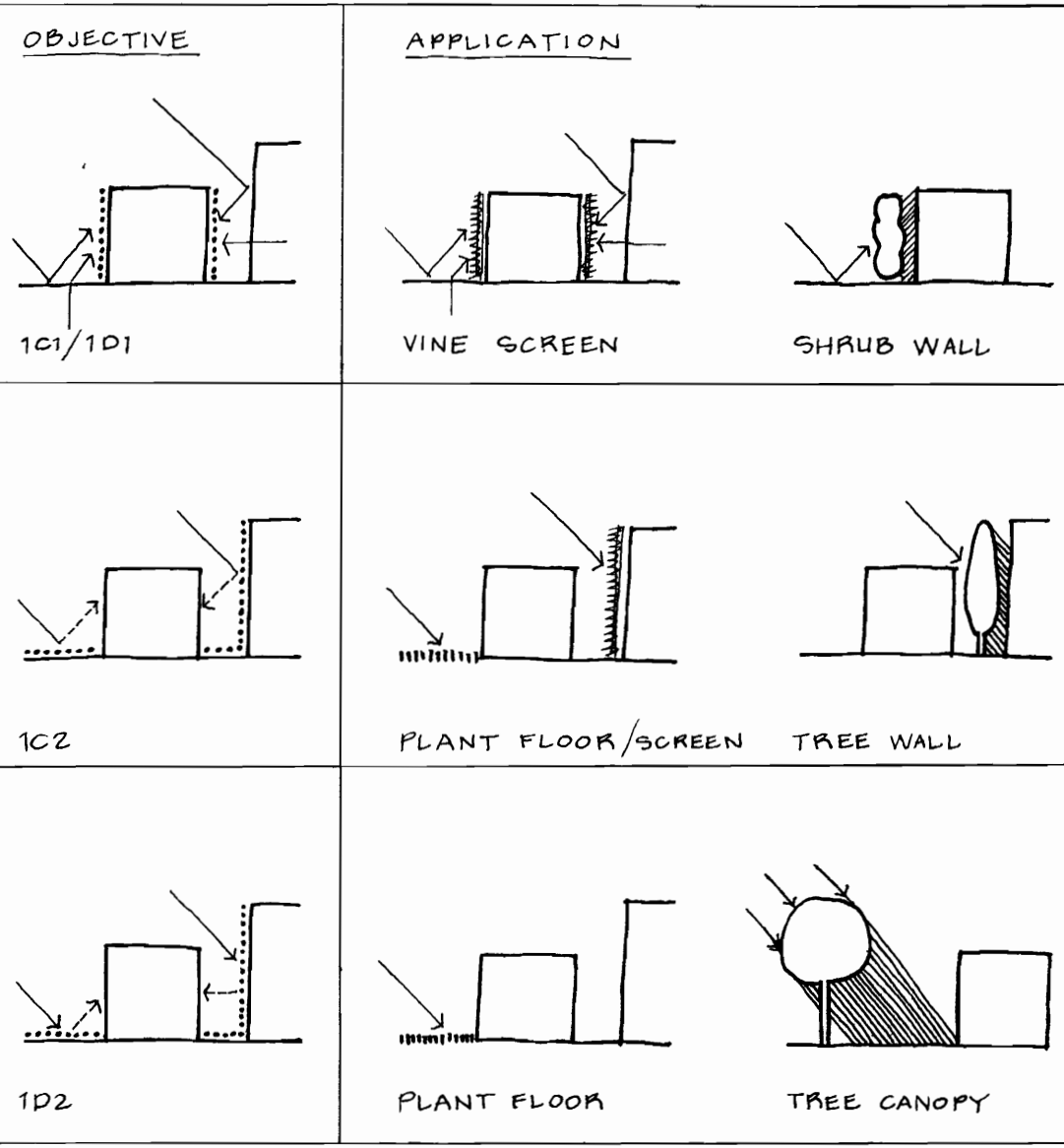
1D. Avoid emitted radiation.

1D1. Block radiation emitted by adjacent ground and walls.

Applications: See 1A1.

1D2. Reduce amount of radiation absorbed, stored, and emitted by adjacent ground and walls.

Applications: See 1C2.

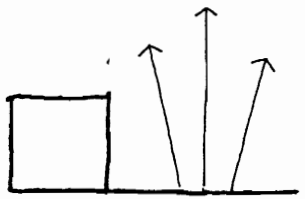


PASSIVE COOLING DESIGN OBJECTIVES

1. AVOID HEAT GAIN THROUGH RADIATION (continued)

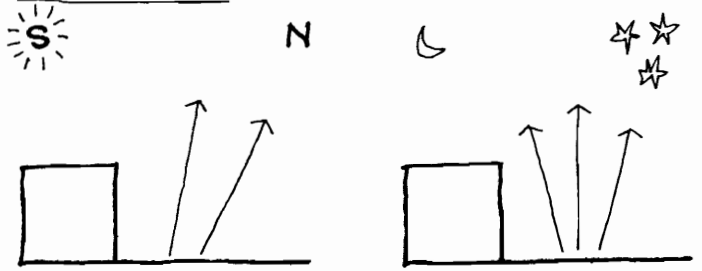
1D3. Encourage emission of heat stored by adjacent ground and walls to heat sinks.

OBJECTIVE



1D3

APPLICATION



NORTH SKY NIGHT SKY

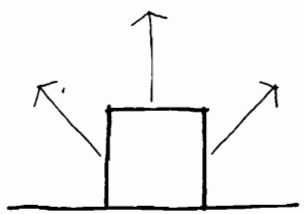
PASSIVE COOLING DESIGN OBJECTIVES

2. ENCOURAGE HEAT LOSS THROUGH RADIATION

2A. Encourage emission of heat stored by building surfaces.

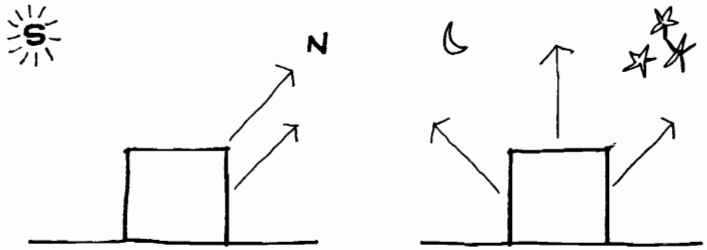
2A1. Expose building walls and roof to heat sinks.

OBJECTIVE



2A1

APPLICATION



PASSIVE COOLING DESIGN OBJECTIVES

3. AVOID HEAT GAIN THROUGH CONVECTION

3A. Prevent infiltration of hot winds.

3A1. Reduce wind speed.

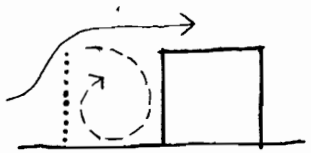
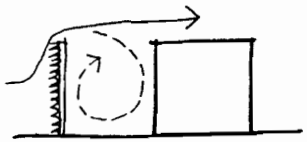
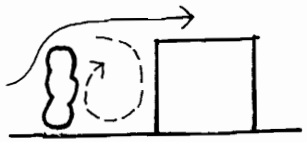
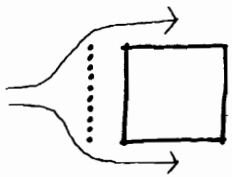
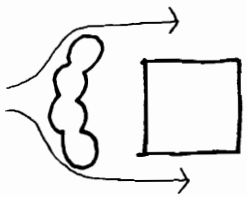
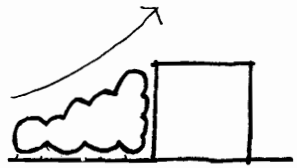
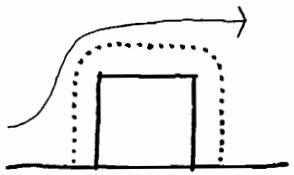
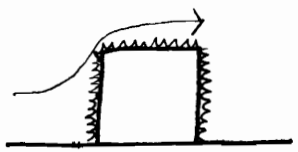
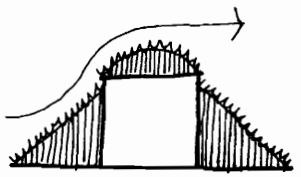
Applications: Tree/shrub Wall, Planted Berm Wall, Tree Screen, Freestanding Lattice, Free-standing Planter Screen.

3A2. Deflect hot winds from building.

Applications: Tree/shrub Wall, Planted Berm Wall, Stepped Wall, Stepped Planters, Tree Screen, Freestanding Lattice, Free-standing Planter Screen.

3A3. Insulate building.

Applications: Tree/shrub wall, Planted Berm Wall, Peat Moss Wall, Planter Wall, Stepped Wall, Stepped Planters, Tree Screen, Freestanding Lattice, Turf Roof, Roof Garden, Trellised Roof Garden, Glazed Planter Roof.

OBJECTIVE	APPLICATION	
 3A1	 VINE SCREEN	 SHRUB WALL
 3A2	 TREE WALL	 SHRUB WALL
 3A3	 VINE SCREEN	 PLANTED BERM

PASSIVE COOLING DESIGN OBJECTIVES

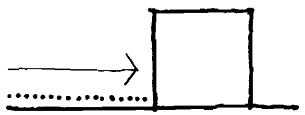
3. AVOID HEAT GAIN THROUGH CONVECTION

3B. Prevent formation of hot winds.

3B1. Reduce surface temperatures in prevailing wind directions.

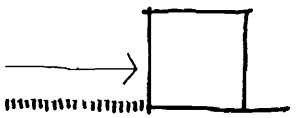
Applications: Tree Screen, Freestanding Lattice, Freestanding Planter Screen, Tree Canopy, Freestanding Trellis, Attached Trellis, Plant Floor, Unit Paver in Grass, Grass Pavement.

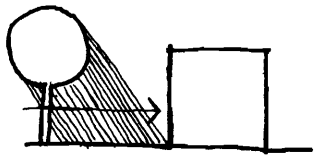
OBJECTIVE



3B1

APPLICATION





PASSIVE COOLING DESIGN OBJECTIVES

4. ENCOURAGE HEAT LOSS THROUGH CONVECTION

4A. Increase ventilation by cool breezes.

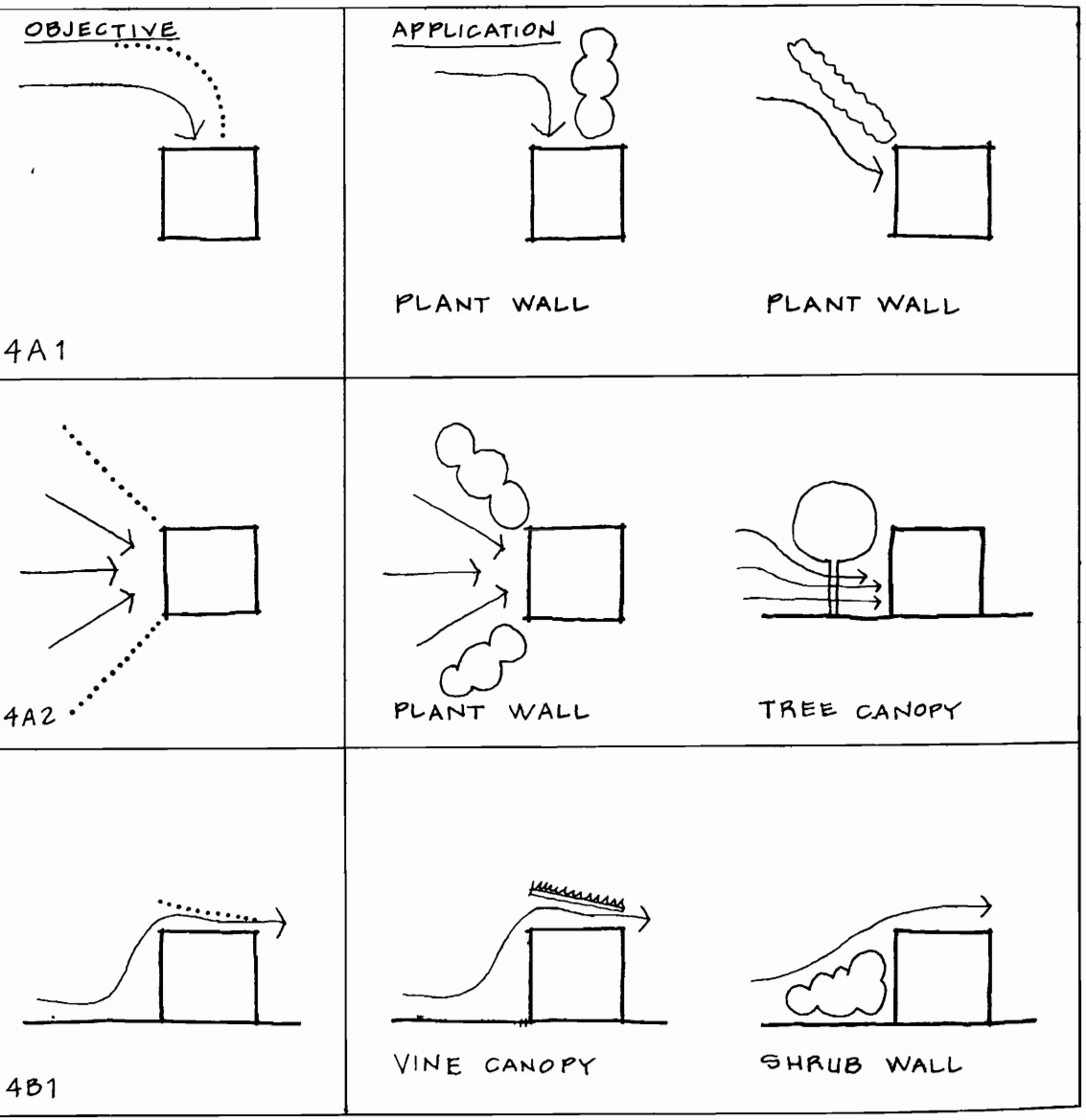
4A1. Direct cool breezes toward building.
Applications: Tree/Shrub Wall, Planted Berm Wall, Tree Screen, Freestanding Lattice, Freestanding Planter Screen, Tree Canopy.

4A2. Increase wind speed.
Applications: See 4A1.

4A3. Permit penetration of cool breezes.
Applications: Window Planters, Window Planter Wall, Tree Screen, Freestanding Lattice, Freestanding Planter Screen, Balcony Edge Planter, Brise Soleil Planter, Vine-covered Wall, Vine-covered Lattice, Vine-Covered Cables, Sliding Wall Planter, Sliding Window Planter, Hinged Planter Screen, Pivoting Screen/Trellis, Tree Canopy, Freestanding Trellis, Attached Trellis, Fixed Window Shade, Shade Court/Sun Pocket

4B. Replace hot air next to building wall and roof with cooler air.

4B1. Direct winds over wall and roof.
Applications: Tree/Shrub Wall, Planted Berm Wall, Stepped Wall, Stepped Planters, Freestanding Planter Screen, Freestanding Lattice, Trellised Roof Garden



PASSIVE COOLING DESIGN OBJECTIVES

5. ENCOURAGE HEAT LOSS THROUGH EVAPORATION

5A. Increase evaporative surfaces.

5A1. Increase number of plants.
Applications: All.

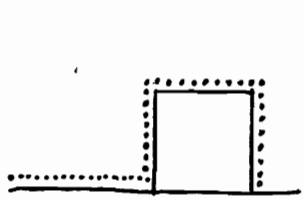
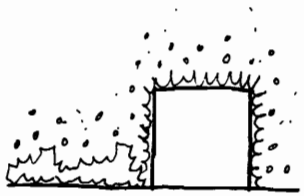
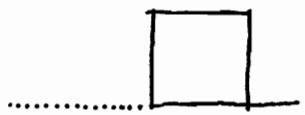
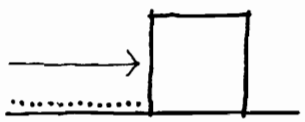
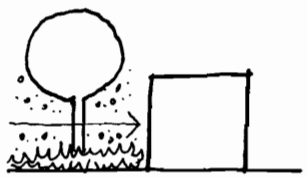
5A2. Plant in open soil rather than pavement.
Applications: All.

5B. Increase rate of evaporation.

5B1. Use plants which have the potential to transpire large amounts of water.
Applications: All.

5B2. Increase convection over evaporative surfaces.
Applications: Tree/Shrub Wall, Planted Berm Wall, Tree Screen, Freestanding Lattice, Freestanding Planter Screen, Tree Canopy.

5B3. Provide ample water supply to plants.
Applications: All.

OBJECTIVE	APPLICATION
 5A1	
 5A2	 PLANT FLOOR
 5B2	 TREE CANOPY

PASSIVE COOLING DESIGN OBJECTIVES

6. AVOID HEAT GAIN THROUGH CONDUCTION

6A. Reduce heat storage in adjacent ground.

6A1. Block incident radiation to ground surface.

Applications: Plant Wall, Berm Wall, Tree Screen, Free-standing Planter Screen, Vine-covered Cables, Sliding Wall Planter, Hinged Planter Screen, Pivoting Screen Trellis, Tree Canopy, Free-standing Trellis, Attached Trellis, Plant Floor, Unit Pavers in Grass.

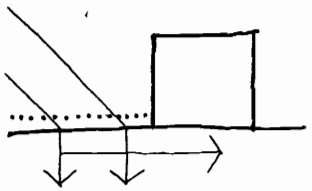
6A2. Reduce conductivity of ground.

6B. Cool adjacent ground.

6B1. Trap air cooled by evapo-transpiration next to ground surface.

Applications: Plant Wall, Berm Wall, Plant Floor.

OBJECTIVE



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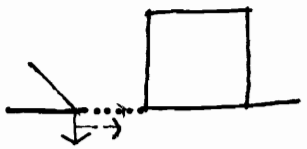
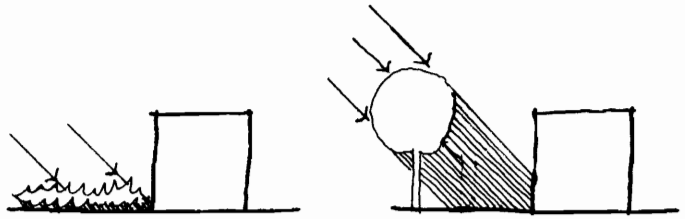
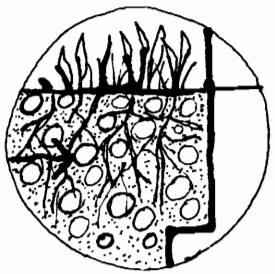


6A2

6B1

APPLICATION





PASSIVE COOLING DESIGN OBJECTIVES

7. ENCOURAGE HEAT LOSS THROUGH CONDUCTION

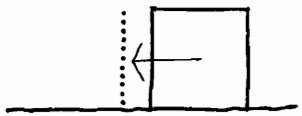
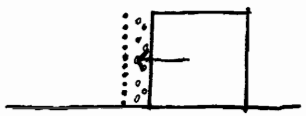
7A. Encourage conduction of heat from building walls and roof.

7A1. Expose building walls and roof to cool conductors.

Applications: Berm Wall, Peat Moss Wall, Turf Roof, Roof Garden, Trellised Roof Garden, Glazed Planter Roof.

7A2. Trap air cooled by evapo-transpiration next to building walls and roof.

Applications: Plant Wall, Berm Wall, Stepped Wall, Stepped Planters, Vine-Covered Wall, Vine-Covered Lattice, Hinged Planter Screen, Pivoting Screen/ Trellis, Roof Lattice, Turf Roof, Roof Garden, Trellised Roof Garden, Glazed Planter Roof.

OBJECTIVE	APPLICATION
 7A1	
 7A2	

PASSIVE COOLING DESIGN APPLICATIONS

A building or landscape design should exploit the maximum number of complementary design strategies for passive cooling. The following pages demonstrate the potential for integrating more than one strategy into the design of seven types of landscape and building elements: walls, windows, screens, roofs, canopies, floors, and courts. Thirty-eight design applications are illustrated. They are not comprehensive. They represent an initial exploration of how plants can be planted on and around small, detached buildings to accomplish passive cooling. A range of options in terms of expense, maintenance, and timing required to achieve effectiveness were identified.

1) Wall: vertical surface which significantly or completely blocks wind and light (e.g., building wall, dense hedge):

- plant wall
- planted berm wall
- peat moss wall
- planter wall
- stepped wall
- stepped planters
- tree/shrub wall

2) Window: an opening in a wall or screen:

- window planter
- window planter wall

3) Screen: vertical surface which allows some penetration of wind and light (e.g., row of deciduous trees, vertical lattice with vines):

- tree screen
- balcony edge
- bris soleil planter
- freestanding planter screen
- vine-covered wall
- vine-covered lattice
- vine-covered cables
- detatched lattice
- sliding wall planter
- sliding window planter
- hinged planter screen
- pivoting screen/trellis

4) Roof: horizontal surface which is impenetrable to light and precipitation (e.g., building roof):

- roof lattice
- turf roof
- roof garden
- trellised roof garden
- glazed planter roof

5) Canopy: horizontal surface which allows some penetration of light and precipitation (e.g., canopy of trees, trellis with vines):

- tree canopy
- freestanding trellis
- attached trellis
- fixed window shade

- sliding window planter
- pivoting screen/trellis

6) Floor: ground surface surrounding building (e.g., lawn, pavement):

- plant floor
- unit pavers in grass
- grass pavement

7) Court: exterior space enclosed by at least two walls or screens:

- shade court/sun pocket
- hinged planter screen

Several issues are addressed for each design application:

Design Objectives and Design Strategies - The general objectives and specific strategies applied are listed to provide a cross-reference with the preceding section, "Passive Cooling Design Objectives."

Suitable Plant Types - General categories of plants are indicated. For specific plant species, their characteristics, requirements, and cost, refer to the next section, "Selected Plants for Passive Cooling."

Timing - The time required for vegetation to accomplish effective passive cooling depends upon the growth rate and shade density of individual plant species and their size and spacing when installed. Grass and other ground covers may provide an immediate effect, while vines may provide a major effect within six months to a year. Trees, however, may require ten years or more to provide effective shade. A landscape plan to promote passive cooling should be phased to provide both immediate and long-term benefits.

Maintenance - A landscape plan for passive cooling need not be expensive, nor need it entail much maintenance. An added benefit is that it may also increase the value of a residential property, as well as enhance its appearance. Installation and maintenance costs depend upon the size and quantity of vegetation planted and the type of structural support, if any, required. Vegetation planted directly in the ground is the cheapest alternative and the easiest to maintain. Any alternative requiring containers, such as planters or window boxes, entails more maintenance. An alternative requiring structural support, especially if integral to the original building structure, such as a turfed roof, is high in both cost and maintenance. Essential to the success of any design using plants for passive cooling is the provision of sufficient water.

Location - The precise location of plants on and around a building is critical to their cooling function and to the resolution of such conflicts as summer cooling and winter heating or to preventing radiant heat gain in daytime and encouraging radiant heat loss at night. For example, a high-branching tree planted close to the southern wall of a building, may shade the wall in summer when the sun is high in the sky, yet permit the penetration of sunlight in winter when the sun is lower in the sky. Depending on the specific passive cooling design objective, plants must be positioned with regard to solar angles and

orientation at a given season and time of day, to angles of reflection from surrounding surfaces, to the prevailing directions of cool summer breezes and hot winds, among other considerations.

Advantages - Design applications which are inexpensive, independent of the existing building structure, attractive, and which serve more than one function are advantageous.

Disadvantages - Design applications which are expensive, integral to the building structure (and which therefore cannot be added to an existing building), and which conflict with other functions are disadvantageous.

Conflicts often arise between passive cooling using vegetation and other functions such as the accommodation of parking and service or passive heating in winter. Unshaded pavement heats the air immediately above it and reflects and emits radiation to nearby building walls, thereby increasing the building's heat load. Yet pavement may be required for driveway and parking. Where pavement is necessary, it should be shaded by a tree canopy or vine-covered trellis. Alternatively, grass pavers may be used instead of the traditional driveway, parking lot, or sidewalk pavement. Grass pavement has been installed in a number of residential and downtown areas, both in the United States and Europe. The City of Dayton is monitoring the effect of its downtown grass pavement parking lot on the surrounding air temperature and radiation environment over a one-year period.

Conflicts with passive heating in winter can also be avoided. Select deciduous species which block the least winter radiation. Locate trees with regard to winter and summer solar angles. Employ sliding vine-covered screens which can be moved to provide shade when needed and to permit light to penetrate when there is no direct sun or in winter (see Sliding Wall Planter, Sliding Window Planter, Hinged Planter Screen). Movable, vine-covered screens can also be used to create an outdoor shade court in summer which is transformed into a sun pocket for fall, winter, and spring (see Shade Court/Sun Pocket).

Some of the passive cooling design strategies are common to all design applications; others apply to only a few. All design applications promote passive cooling by increasing both the evaporative surfaces and the rate of evaporation. This is accomplished by increasing the number of plants, planting in open soil rather than pavement, and providing an ample water supply.

PASSIVE COOLING DESIGN APPLICATIONS

WALL: TREE/SHRUB WALL

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
3A. Prevent infiltration of hot winds.
4A. Increase ventilation by cool breezes.
4B. Replace hot air next to building walls and roof with cooler air.
5A. Increase evaporative surfaces.
5B. Increase rate of evaporation.
6A. Reduce heat storage in adjacent ground.
6B. Cool adjacent ground.
7A. Encourage conduction of heat from building walls and roof.

Suitable Plant Types

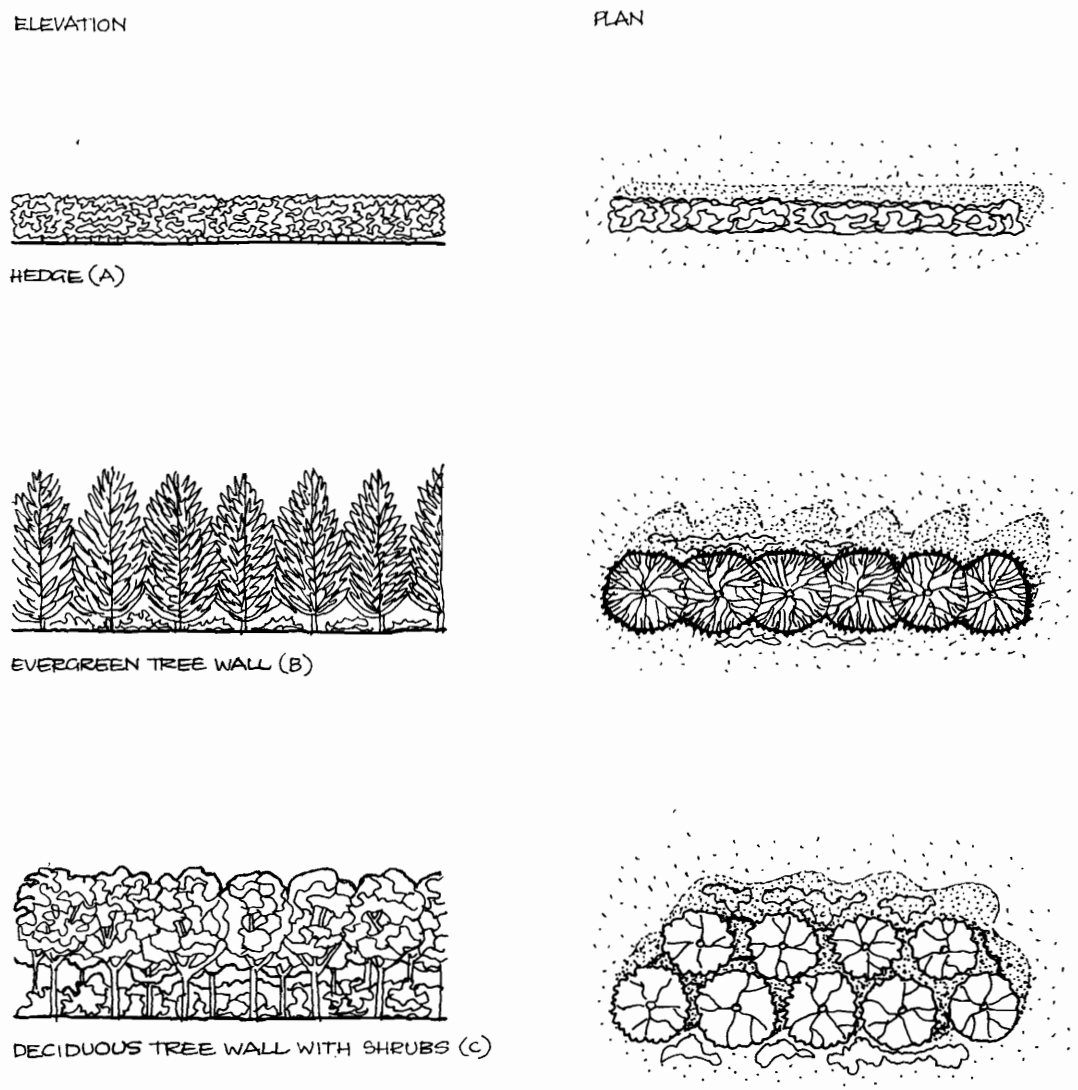
A) Dense evergreen or deciduous shrubs
B) Dense evergreen trees
C) Densely planted deciduous trees and tall shrubs

Timing

A) 5-10 years
B) 15-20 years
C) 15-20 years

Maintenance

Low (high for sheared hedge)



PASSIVE COOLING DESIGN APPLICATIONS

WALL: PLANT WALL--SHADE WALL

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1C2. Reduce radiation reflected by surrounding ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
1D2. Reduce amount of radiation absorbed, stored and emitted by adjacent ground and walls.
3A3. Insulate building.
6A1. Block incident radiation to ground surface.
7A2. Trap air cooled by evapo-transpiration next to building walls and roof.

Location

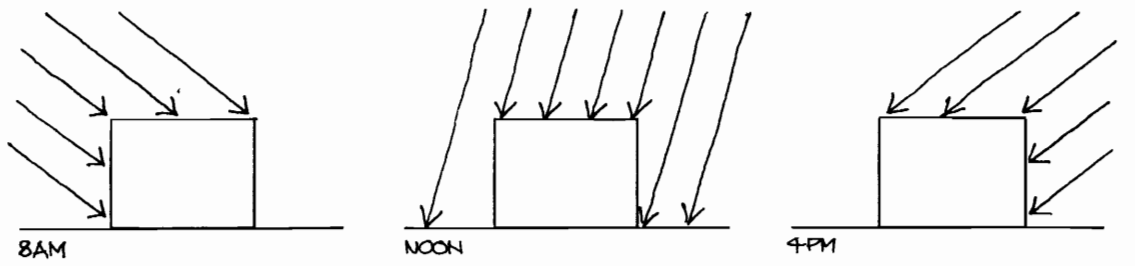
- Position to block direct sunlight (see diagrams).
- Position between building and emittive surfaces, such as walls or pavement.
- Distance from building depends upon solar angles and height of shade wall.

Advantages

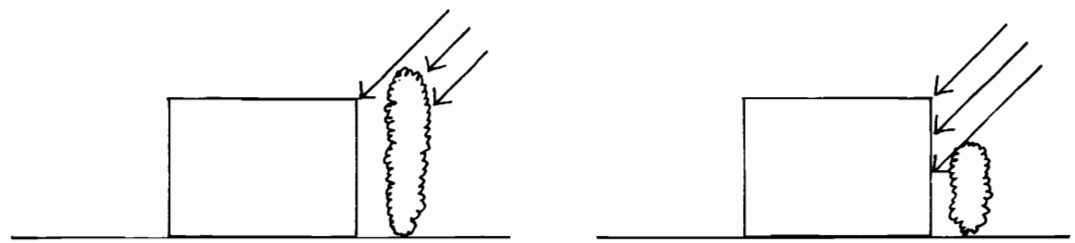
- Relatively inexpensive.
- May serve other functions.
- Can be added to an existing building.

Disadvantages

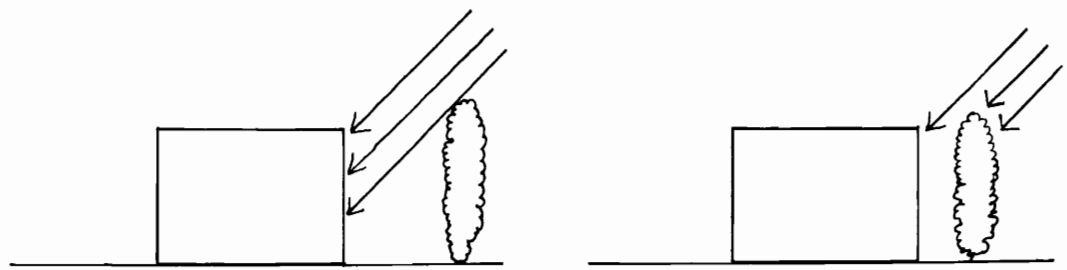
- Tree wall: relatively long time (15-20 years) to become effective.
- May block winter sun.



SUMMER SOLAR ANGLES (WASHINGTON D.C. JUNE 22)



HEIGHT OF PLANT WALL



DISTANCE FROM BUILDING

PASSIVE COOLING DESIGN APPLICATIONS

WALL: TREE/SHRUB WALL--WIND FUNNEL

Design Strategies

4A1. Direct cool breezes toward building.
4A2. Increase wind speed.
4B1. Direct winds over walls and roof.
5B2. Increase convection over evaporative surfaces.

Location

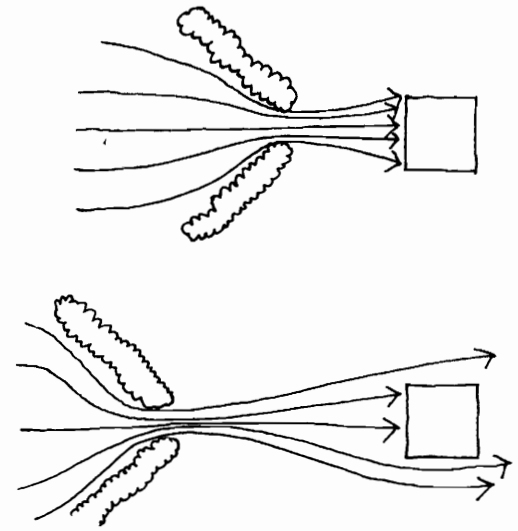
- Upwind of building in direction of prevailing summer breezes.
- Opening of funnel should be narrow in proportion to height of wall and located close to the building to achieve maximum effect.

Advantages

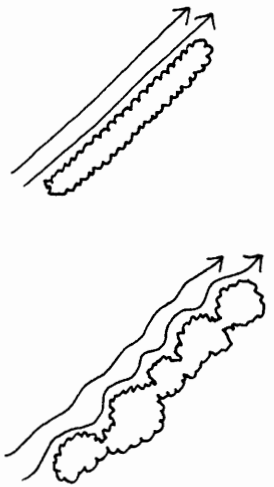
- Relatively inexpensive.
- May serve shade function as well.
- Can be added to an existing building.

Disadvantages

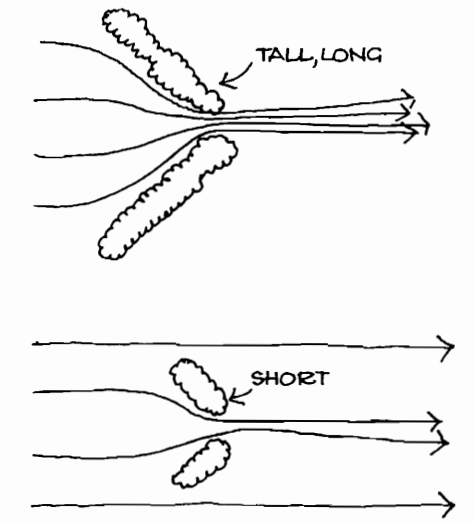
- Tree wall: relatively long time (15-20 years) to become effective.



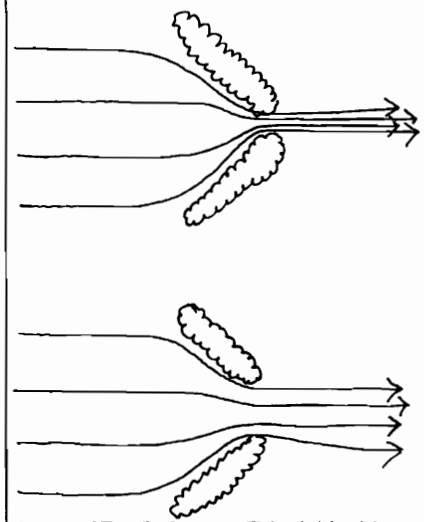
EFFECT OF LOCATION ON SPEED



EFFECT OF SURFACE TEXTURE ON SPEED



EFFECT OF LENGTH + HEIGHT ON SPEED



EFFECT OF SIZE OF OPENING ON SPEED

PASSIVE COOLING DESIGN APPLICATIONS

WALL: TREE/SHRUB WALL-WIND SCOOP

Design Strategies

4A1. Direct cool breezes toward building.
4A2. Increase wind speed.

Location

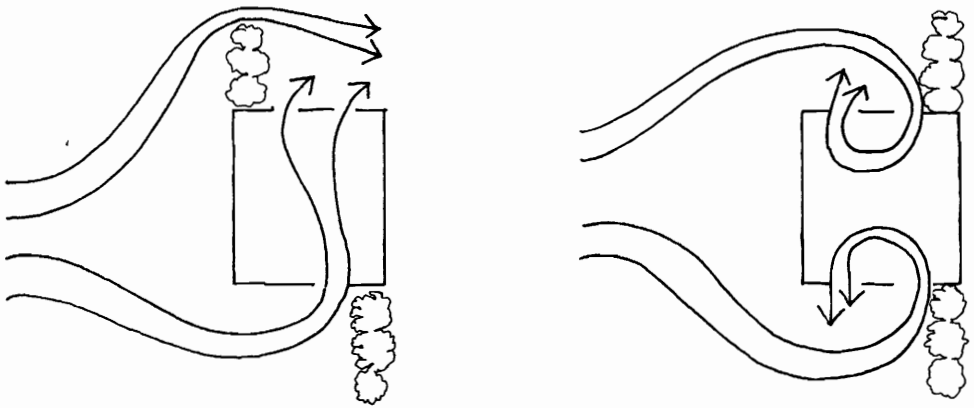
- Locate to capture prevailing breezes (see diagram).

Advantages

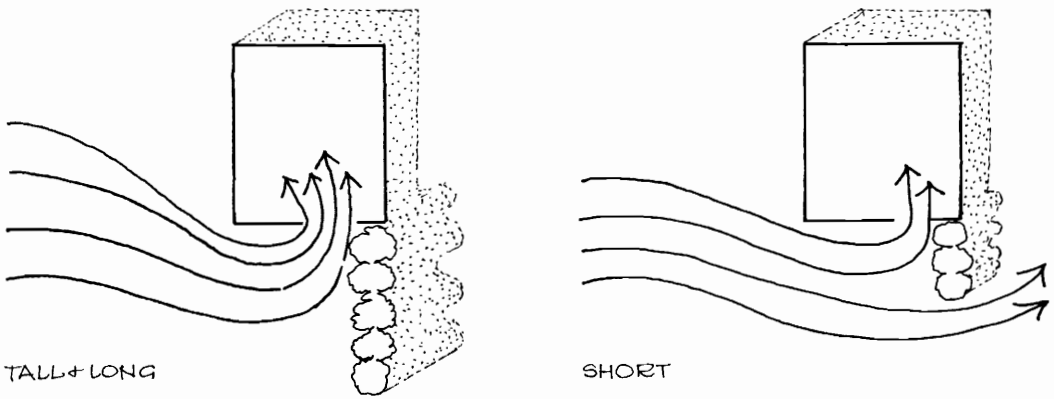
- Relatively inexpensive.
- May serve shade function as well.
- Can be added to an existing building.

Disadvantages

- May block breezes from other than prevailing direction.



LOCATION OF WALL IN RELATION TO WINDOW OPENINGS AND INTERIOR VENTILATION



EFFECT OF LENGTH & HEIGHT ON AMOUNT OF VENTILATION

PASSIVE COOLING DESIGN APPLICATIONS

WALL: TREE/SHRUB WALL--WIND RAMP

Design Strategies

3A2. Deflect hot winds from building.

4B1. Direct winds over walls and roof.
5B2. Increase convection over evaporative surfaces.
7A2. Trap air cooled by evapo-transpiration next to building walls and roof.

Location

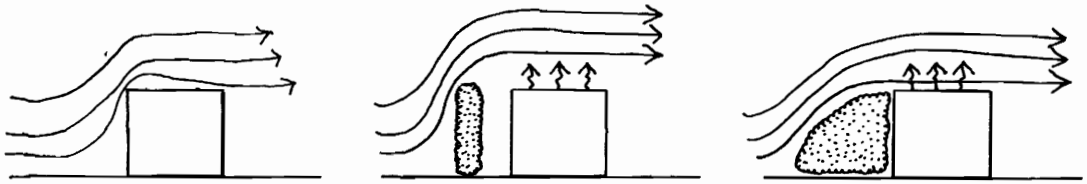
- Upwind of building in direction of prevailing hot winds.
- Distance from building depends upon whether a layer of cooled, insulating air between plants and building ventilation is desired.

Advantages

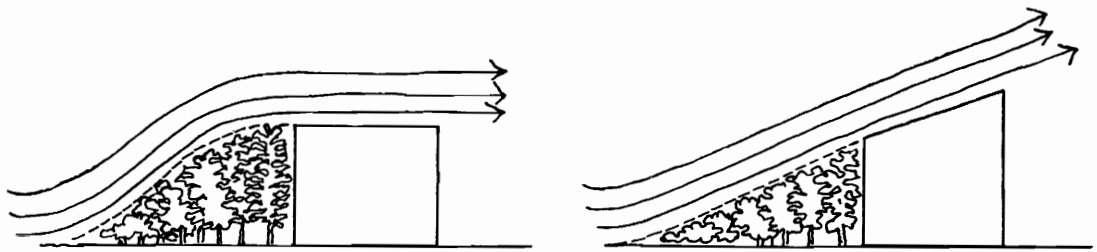
- Relatively inexpensive.
- Serves multiple function of deflecting hot winds, removing hot air over roof surface, and shading building walls.
- Can be addded to an existing building.

Disadvantages

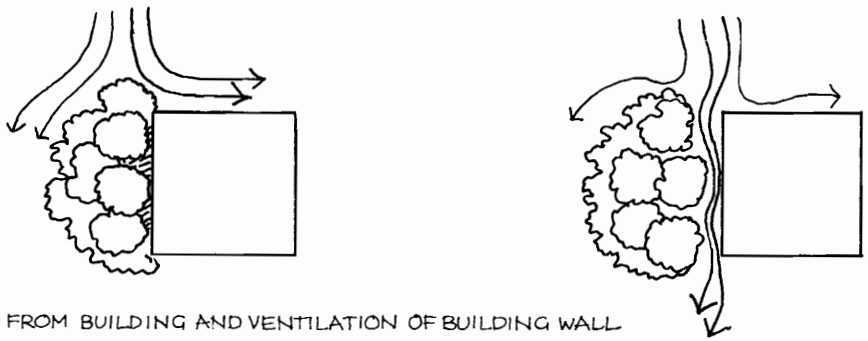
- Length of time to achieve effectiveness (depends on height of building).
- May reduce ventilation from cool breezes.



AIR MOVEMENT OVER OBSTACLES



SLOPE OF SURFACE + ROOF LINE



DISTANCE FROM BUILDING AND VENTILATION OF BUILDING WALL

PASSIVE COOLING DESIGN APPLICATIONS

WALL: TREE/SHRUB WALL--WINDBREAK

Design Strategies

3A1. Reduce wind speed.
3A2. Deflect hot winds from building.

Location

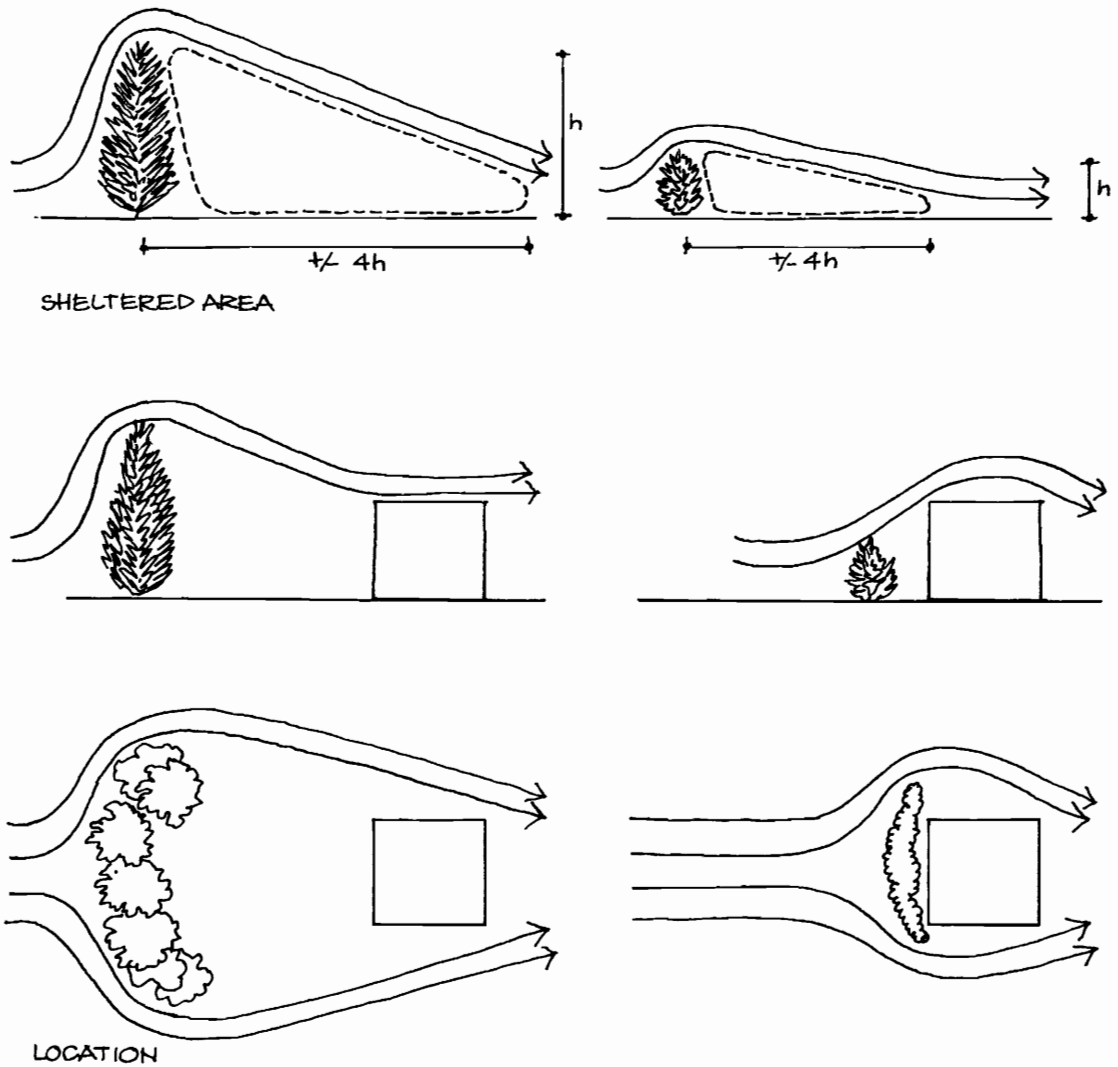
- Upwind of building in direction of prevailing hot winds.
- Only applicable in hot climates where advantages of blocking the hot winds outweigh disadvantages from loss of ventilation.

Advantages

- Relatively inexpensive.
- Can be added to an existing building.

Disadvantages

- May block cool breezes.
- Tree wall: relatively long time (15-20 years) to become effective.
- May block cool breezes.



PASSIVE COOLING DESIGN APPLICATIONS

WALL: PLANTED BERM WALL

Purpose

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
3A. Prevent infiltration of hot winds.
4A. Increase ventilation by cool breezes.
4B. Replace hot air next to building walls and roof with cooler air.
5A. Increase evaporative surfaces.
5B. Increase rate of evaporation.
6A. Reduce heat storage in adjacent ground.
6B. Cool adjacent ground.
7A. Encourage conduction of heat from building walls and roof.

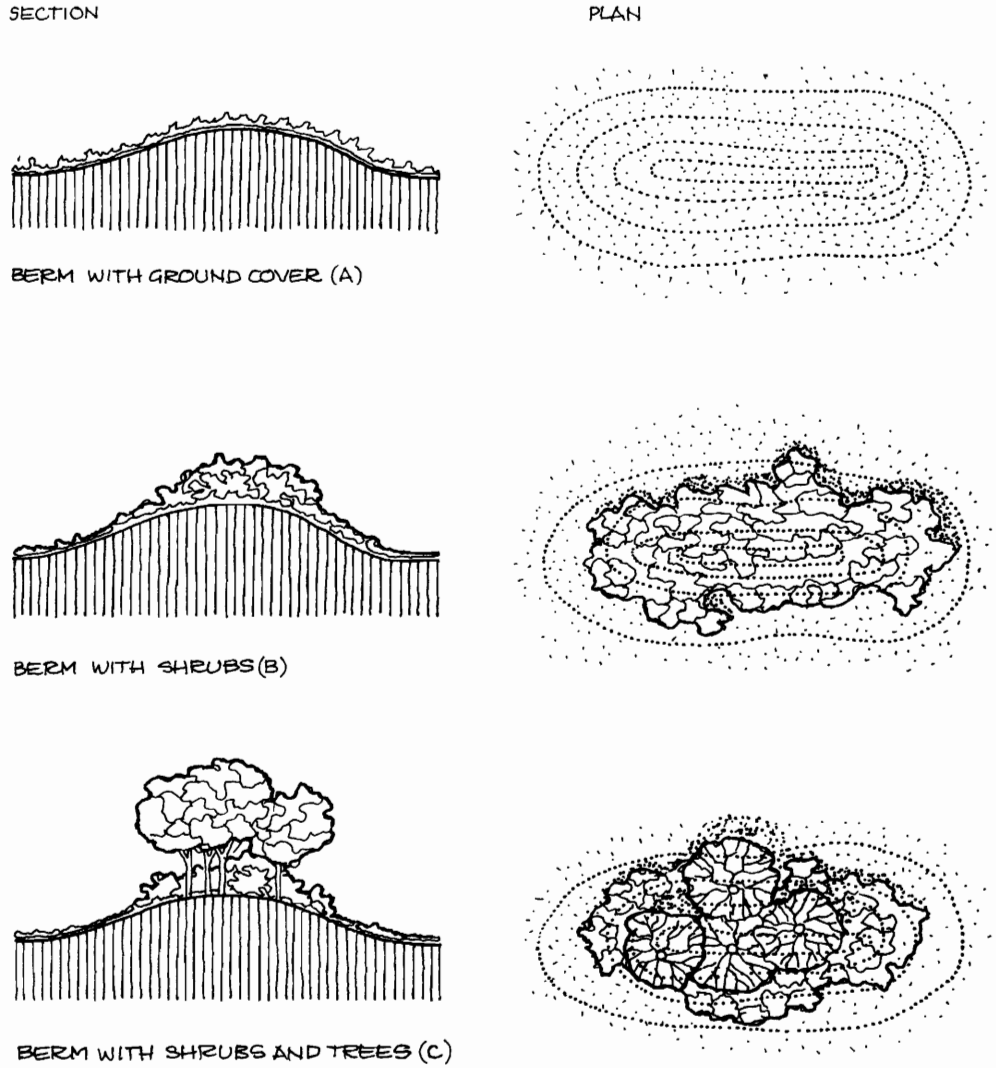
Suitable Plant Types

A) Groundcovers
B) Dense evergreen or deciduous shrubs
C) Densely planted deciduous trees and tall shrubs

Timing

A) Effective within six months.
B) 3-5 years
C) 10-15 years

Maintenance - Low



PASSIVE COOLING DESIGN APPLICATIONS

WALL: PLANTED BERM WALL (continued)

Design Strategies

See: Tree/shrub wall: shade wall
Tree/shrub wall: wind funnel
Tree/shrub wall: wind scoop
Tree/shrub wall: wind ramp
Tree/shrub wall: windbreak

Location

Depends upon function. See: tree/shrub wall: windbreak, wind funnel, wind scoop, wind ramp, shade wall.

Advantages

- Earth berms give additional height.
- Uses left-over fill.
- See tree/shrub wall: shade wall, wind funnel, wind scoop, wind ramp, windbreak.

Disadvantages

- Expensive if fill must be imported.
- See tree/shrub wall: shade wall, wind funnel, wind scoop, wind ramp, windbreak.

PASSIVE COOLING DESIGN APPLICATIONS

WALL: PEAT MOSS WALL

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
3A. Prevent infiltration of hot winds.
5A. Increase evaporative surfaces.
7A. Encourage conduction of heat from building walls and roof.

Suitable Plant Types

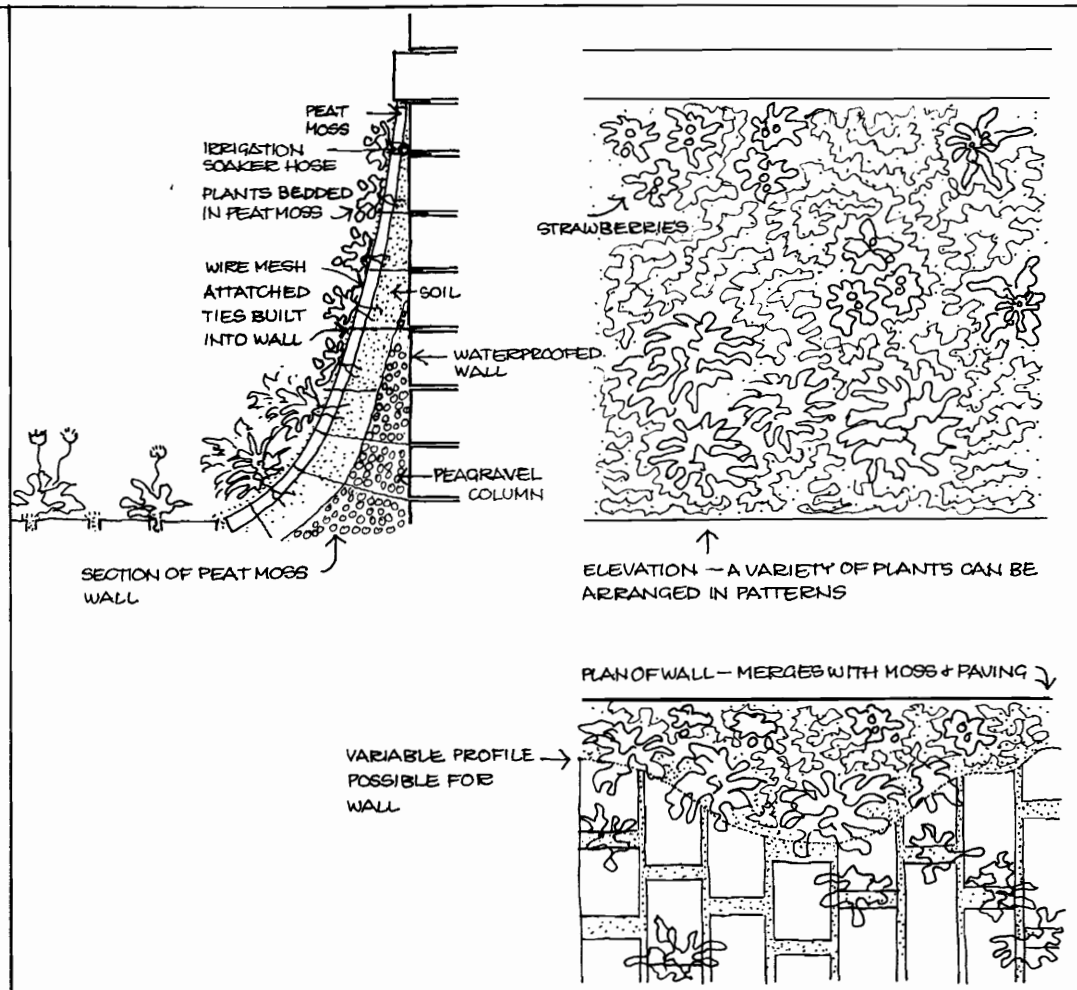
Groundcovers

Timing

6 months to 1 year

Maintenance

Moderate; requires frequent watering and fertilization



PASSIVE COOLING DESIGN APPLICATIONS

WALL: PEAT MOSS WALL (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
3A3. Insulate building.
5A2. Plant in open soil rather than pavement.
7A1. Expose building walls and roof to cool conductors.

Location: South, east or west wall

Advantages
- Relatively inexpensive
- No extensive structural requirements
- Renewable
- Potential seasonal plant variety
- Blends with surrounding landscape
- Can be added to an existing structure

Disadvantages
- Relatively impermanent
- Limited height
- Requires good waterproofing
- Moderately high plant maintenance

PASSIVE COOLING DESIGN APPLICATIONS

WALL: PLANTER WALL

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation
1D. Avoid emitted radiation.
3A. Prevent infiltration of hot winds.
5A. Increase evaporative surfaces.
7A. Encourage conduction of heat from building walls and roof.

Suitable Plant Types

Groundcovers, hanging shrubs, and vines

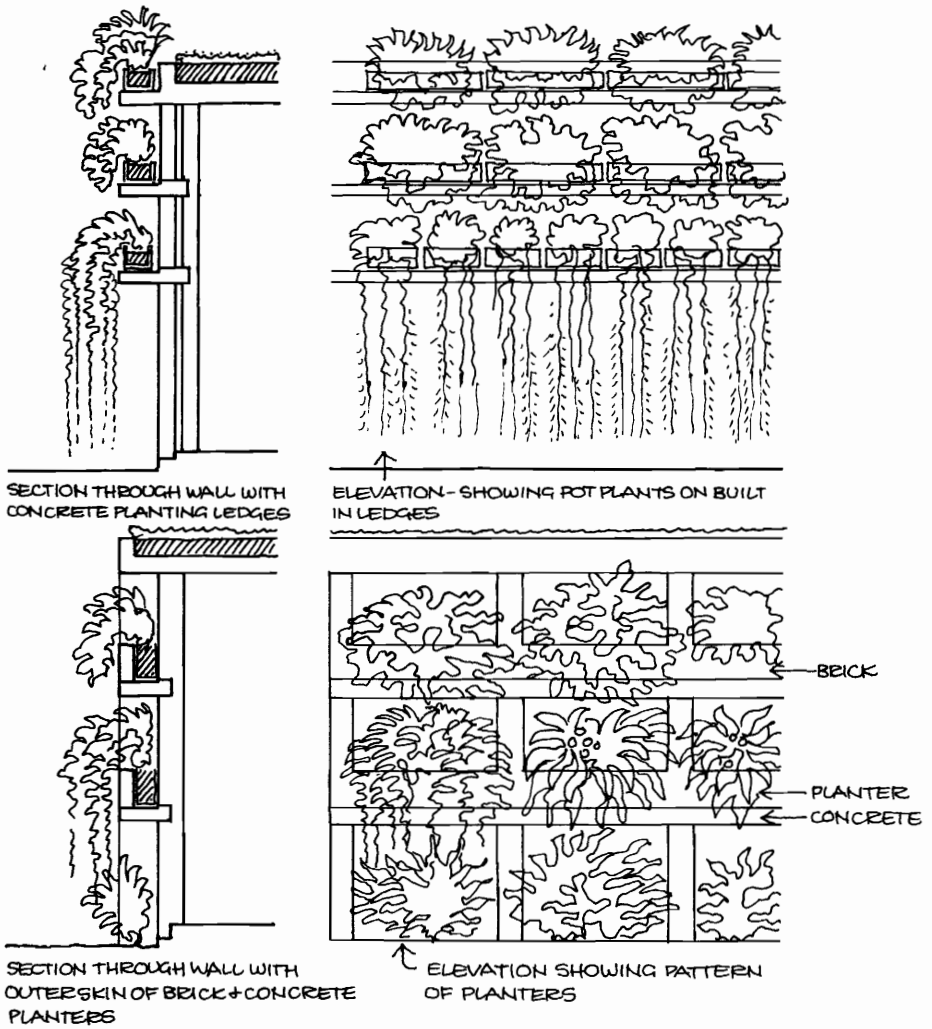
Timing

One year

Maintenance

High; must be watered and fertilized frequently

A) Plant containers are interchangeable
B) Replanting required at intervals



PASSIVE COOLING DESIGN APPLICATIONS

WALL: PLANTER WALL (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky,
1C1. Block radiation reflected by adjacent ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
3A3. Insulate building.
7A2. Trap air cooled by evapo-transpiration next to building walls and roof.

Location - East or west wall

Advantages

- Flexible, plants can be changed or moved for variation in shading
- Permanent wall feature
- Provides insulation

Disadvantages

- Integral to original structure
- Requires frequent watering

PASSIVE COOLING DESIGN APPLICATIONS

WALL: STEPPED WALL

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
3A. Avoid infiltration of hot winds.
4B. Replace hot air next to building walls and roof with cooler air.
5A. Increase evaporative surfaces.
7A. Encourage conduction of heat from building walls and roof.

Suitable Plant Types

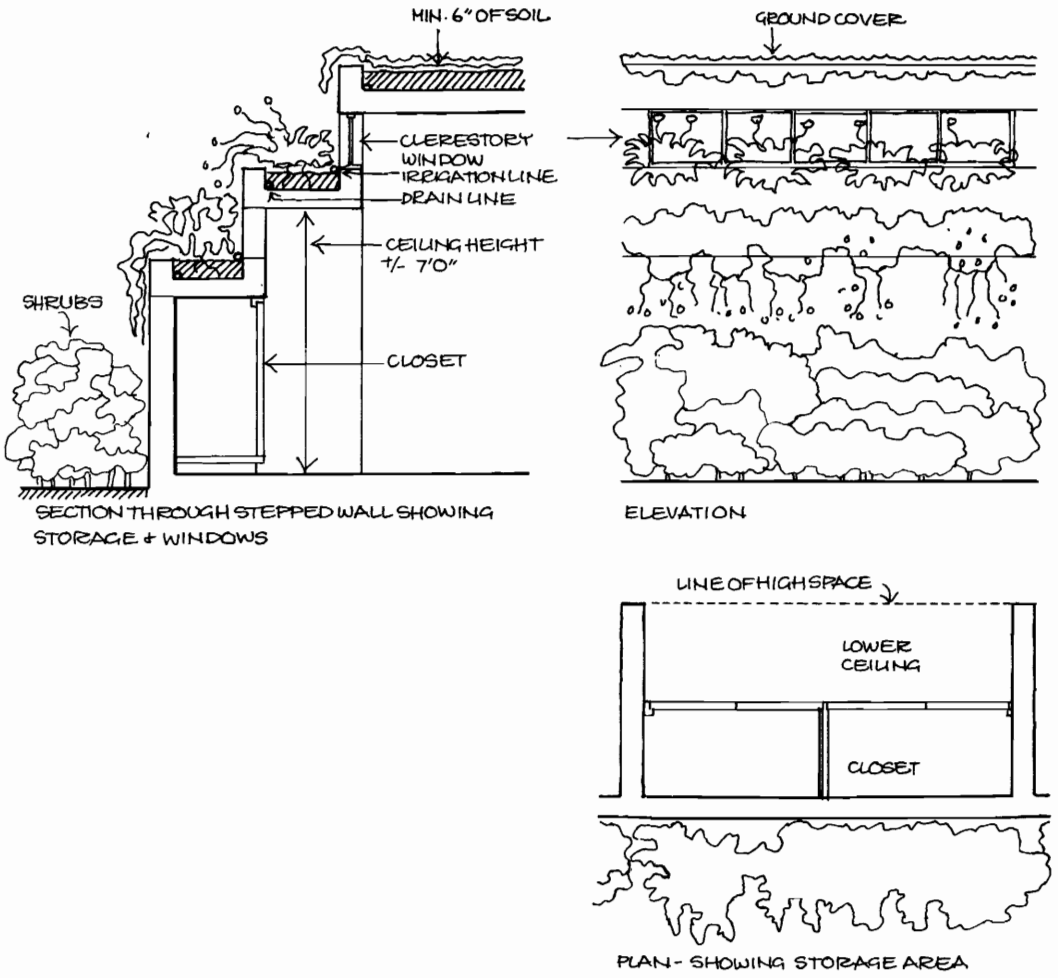
Groundcovers, shrubs, and vines

Timing

1-3 years

Maintenance

High; depends upon plant material selected



PASSIVE COOLING DESIGN APPLICATIONS

WALL: STEPPED WALL (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
3A2. Deflect hot winds from building.
3A3. Insulate building.
4B1. Direct winds over walls and roof.
7A2. Trap air cooled by evapo-transpiration next to building walls and roof.

Location - East or west wall

Advantages

- External and internal functions are complementary
- Permanent wall feature
- Provides insulation

Disadvantages

- Expensive
- Integral to initial structure

References

PASSIVE COOLING DESIGN APPLICATIONS

WALL: STEPPED PLANTER

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
3A. Avoid infiltration of hot winds.
4B. Replace hot air next to building walls and roof with cooler air.
5A. Increase evaporative surfaces.
7A. Encourage conduction of heat from building walls and roof.

Suitable Plant Types

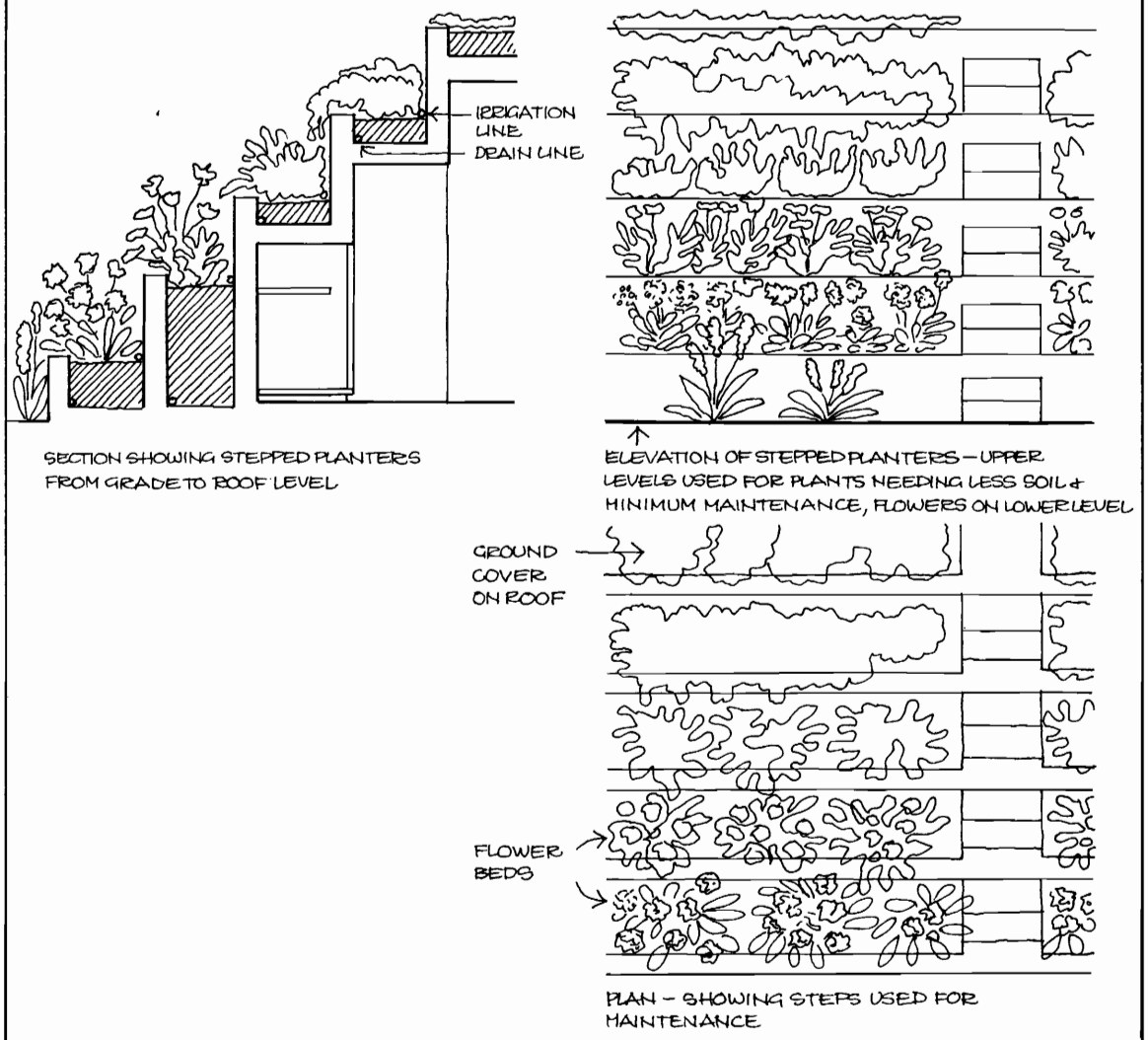
Groundcovers, shrubs, and vines

Timing

1-3 years

Maintenance

High; requires watering system and careful selection of low maintenance plants at upper levels



PASSIVE COOLING DESIGN APPLICATIONS

WALL: STEPPED PLANTERS (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
3A2. Deflect hot winds from building.
3A3. Insulate building.
4B1. Direct winds over walls and roof.
7A2. Trap air cooled by evapo-transpiration next to building walls and roof.

Location - East or west walls

Advantages

- Building blends into landscape
- Provides insulation

Disadvantages

- Expensive
- Integral to initial structure

PASSIVE COOLING DESIGN APPLICATIONS

WINDOW: WINDOW PLANTERS

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
5A. Increase evaporative surfaces.
4A. Increase ventilation by cool breezes.

Suitable Plant Types

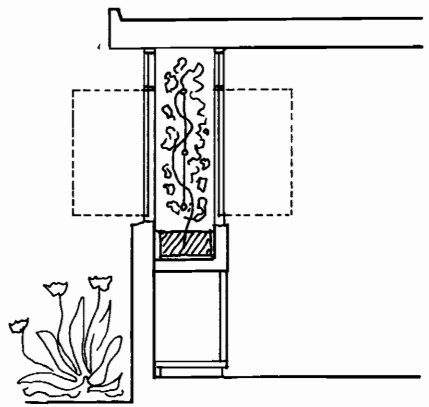
A) Interior vines
B) Annuals, perennials, groundcover, or low shrubs

Timing

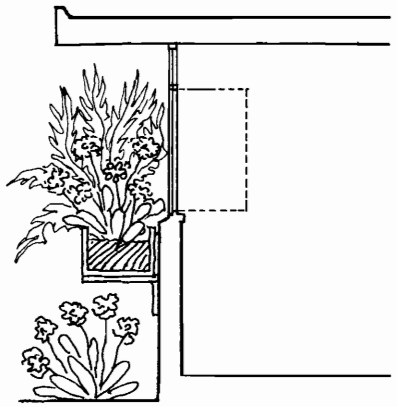
6 months - 1 year

Maintenance

High; frequent watering



A) SECTION THROUGH PLANTER BETWEEN DOUBLE GLAZING — OPENING STANDARD WINDOWS, STORAGE BELOW PLANTER



B) SECTION THROUGH TYPICAL WINDOW BOX

PASSIVE COOLING DESIGN APPLICATIONS

WINDOW: WINDOW PLANTERS (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
4A3. Permit penetration of cool breezes.

Location - South, east or west walls

Advantages

- Inexpensive
- May be added to an existing building

PASSIVE COOLING DESIGN APPLICATIONS

WINDOW: WINDOW PLANTER WALL

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
5A. Increase evaporative surfaces.
4A. Increase ventilation by cool breezes.

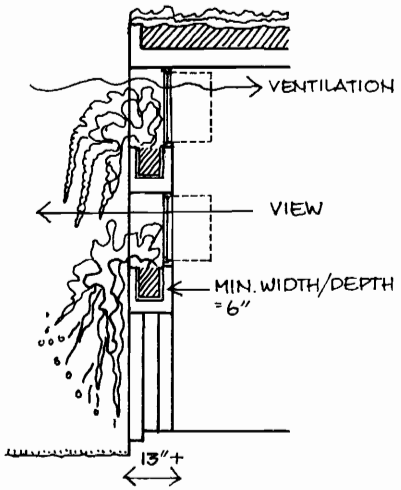
Suitable Plant Type - Groundcover, vines

Timing

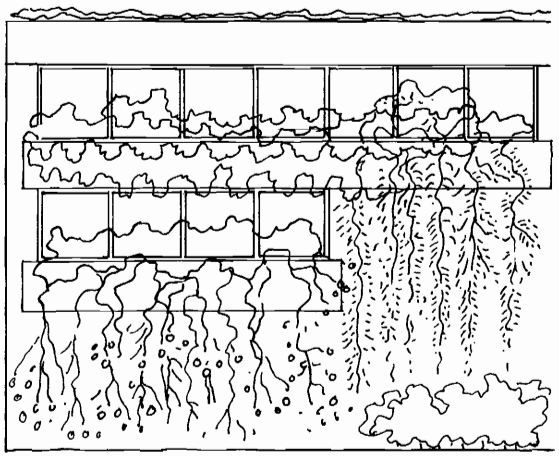
1 year

Maintenance

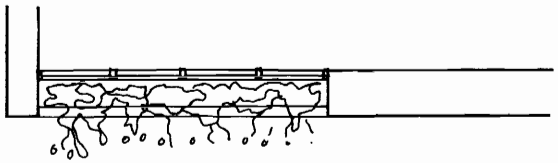
Moderate; requires window cleaning



SECTION THROUGH CAVITY WALL WITH CONCRETE PLANTERS



ELEVATION OF PLANTERS + WINDOWS



PLAN AT LOWER WINDOW LEVEL

PASSIVE COOLING DESIGN APPLICATIONS

WINDOW: WINDOW PLANTER WALL (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
4A3. Permit penetration of cool breezes.

Location - South, east or west walls

Advantages

- Windows can be opened
- Allows breezes and sun while providing shade and some insulation

Disadvantages

- Expensive
- Integral to original building construction

PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: TREE SCREEN

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
3A. Prevent infiltration of hot winds.
3B. Prevent formation of hot winds.
4A. Increase ventilation by cool breezes.
5A. Increase evaporative surfaces.
5B. Increase rate of evaporation.
6A. Reduce heat storage in adjacent ground.
7A. Encourage conduction of heat from building walls and roof.

Suitable Plant Types

A) Low-branching columnar trees
B) High-branching trees

Timing

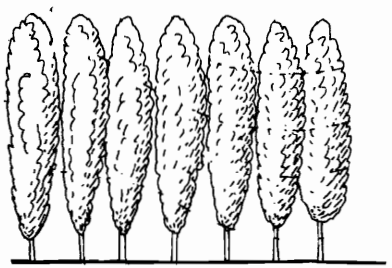
10 to 15 years depending on growth rate of tree and size when planted

Maintenance

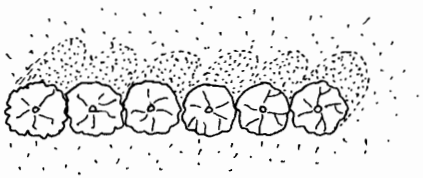
Low

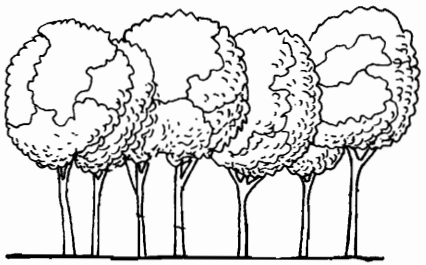
ELEVATION

PLAN

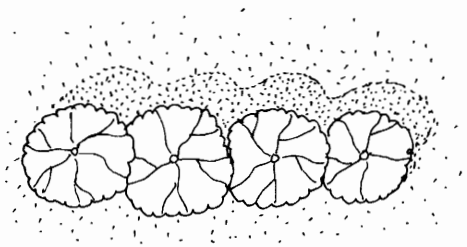


COLUMNAR SHADE TREE (A)





TRUNK SCREEN (B)



PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: TREE SCREEN (continued)

Design Strategies

4A3. Permit penetration of cool breezes.

shade screen:

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1C2. Reduce radiation reflected by surrounding ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
1D2. Reduce amount of radiation absorbed, stored and emitted by adjacent ground and walls.
3A3. Insulate building.
3B1. Reduce surface temperatures in prevailing wind directions.
6A1. Block incident radiation to ground surface.
7A2. Trap air cooled by evapo-transpiration next to building walls and roof.

wind funnel screen:

4A1. Direct cool breezes toward building.
4A2. Increase wind speed.
4B1. Direct winds over walls and roof.
5B2. Increase convection over evaporative surfaces.

wind scoop screen:

4A1. Direct cool breezes toward building.
4A2. Increase wind speed.

windbreak screen:

3A1. Reduce wind speed.
3A2. Deflect hot winds from building.

Location

Depends upon function.
See tree/shrub wall: windbreak, wind funnel, wind scoop, shade wall.

Advantages

- Can be added to existing structure.
- May serve multiple functions.
- See advantages under tree-shrub wall.

Disadvantages

- Relatively long time to become effective.
- See disadvantages under tree/shrub wall.

PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: FREESTANDING LATTICE

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
3A. Prevent infiltration of hot winds.
3B. Prevent formation of hot winds.
4A. Increase ventilation by cool breezes.
5A. Increase evaporative surfaces.
5B. Increase rate of evaporation.
6A. Reduce heat storage in adjacent ground.
7A. Encourage conduction of heat from building walls and roof.

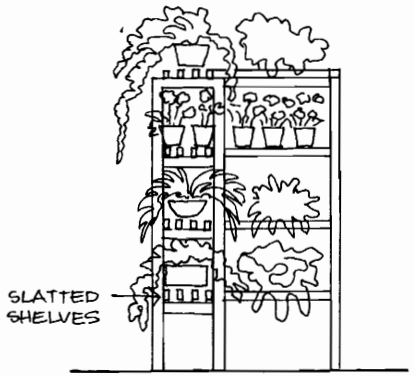
Suitable Plant Types

Houseplants, annuals, groundcovers

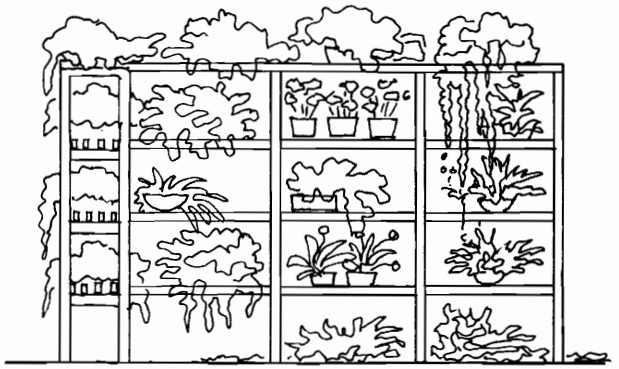
Timing - Effective immediately

Maintenance

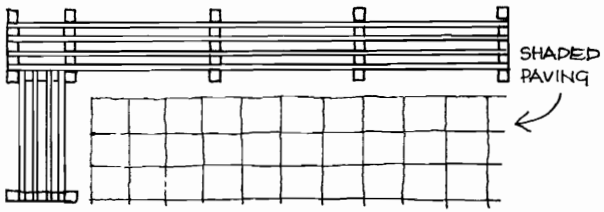
Very high; many small containers require frequent watering; structure is exposed to weather



SECTION THROUGH FREESTANDING PLANTER SCREEN



ELEVATION- SHOWING SHELVES FOR POTTED PLANTS



PLAN - ONE POSSIBLE CONFIGURATION

PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: FREESTANDING LATTICE (continued)

Design Strategies

4A3. Permit penetration of cool breezes.

shade screen:

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1C2. Reduce radiation reflected by surrounding ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
1D2. Reduce amount of radiation absorbed, stored and emitted by adjacent ground and walls.
3A3. Insulate building.
3B1. Reduce surface temperatures in prevailing wind directions.
6A1. Block incident radiation to ground surface.
7A2. Trap air cooled by evapo-transpiration next to building walls and roof.

wind funnel screen:

4A1. Direct cool breezes toward building.
4A2. Increase wind speed.
4B1. Direct winds over walls and roof.
5B2. Increase convection over evaporative surfaces.

wind scoop screen:

4A1. Direct cool breezes toward building.
4A2. Increase wind speed.

windbreak screen:

3A1. Reduce wind speed.
3A2. Deflect hot winds from building.

Location

- Depends upon function.
- See tree/shrub wall: windbreak, wind funnel, wind scoop, shade wall.

Advantages

- Relatively inexpensive.
- Flexible in use of plant material.
- Summer home for house plants.
- See advantages under tree/shrub wall.

Disadvantages

- Relatively high maintenance.
- Requires frequent watering.
- See disadvantages under tree/shrub wall.

PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: FREESTANDING PLANTER SCREEN

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
3A. Prevent infiltration of hot winds.
3B. Prevent formation of hot winds.
4A. Increase ventilation by cool breezes.
5A. Increase evaporative surfaces.
5B. Increase rate of evaporation.
6A. Reduce heat storage in adjacent ground.

Suitable Plant Types

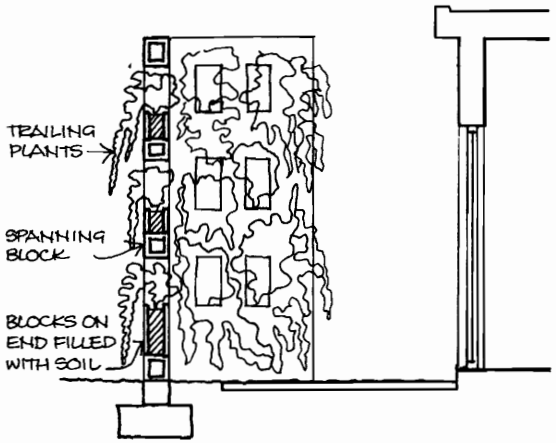
Groundcovers, vines.

Timing

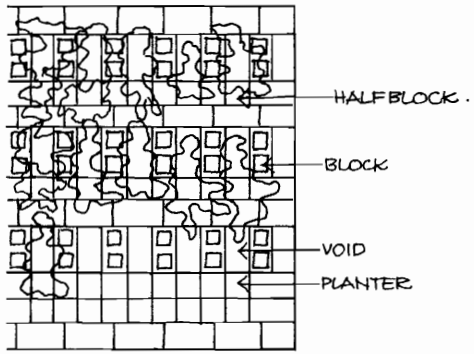
Six months to one year.

Maintenance

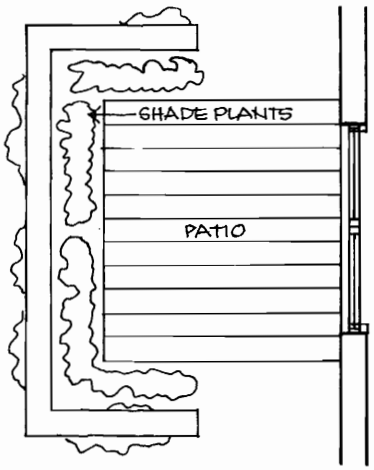
Very high, requires frequent watering and fertilization.



SECTION THROUGH CONCRETE BLOCK SCREEN



ELEVATION OF CONCRETE BLOCK PLANTER SCREEN USING A COMBINATION OF FULL & HALF BLOCKS



PLAN - SCREEN CREATES PROTECTED OUTDOOR SPACE

PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: FREESTANDING PLANTER SCREEN (continued)

Design Strategies

4A3. Permit penetration of cool breezes.

shade screen:

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radation reflected by adjacent ground and walls.
1C2. Reduce radiation reflected by surrounding ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
1D2. Reduce amount of radiation absorbed, stored and emitted by adjacent ground and walls.
3A3. Insulate building.
3B1. Reduce surface temperatures in prevailing wind directions.
6A1. Block incident radiation to ground surface.

wind funnel screen:

4A1. Direct cool breezes toward building.
4A2. Increase wind speed.
4B1. Direct winds over walls and roof.
5B2. Increase convection over evaporative surfaces.

wind scoop screen:

4A1. Direct cool breezes toward building.
4A2. Increase wind speed.

windbreak screen:

3A1. Reduce wind speed.
3A2. Deflect hot winds from building.

Location

- Depends upon function.
- See tree/shrub wall: windbreak, wind funnel, wind scoop, shade wall.

Advantages

- Relatively inexpensive.
- No structural maintenance.
- Can be added to existing structure.

Disadvantages

- Requires frequent watering.

PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: BALCONY EDGE PLANTER

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
4A. Increase ventilation by cool breezes.
5A. Increase evaporative surfaces.

Suitable Plant Types

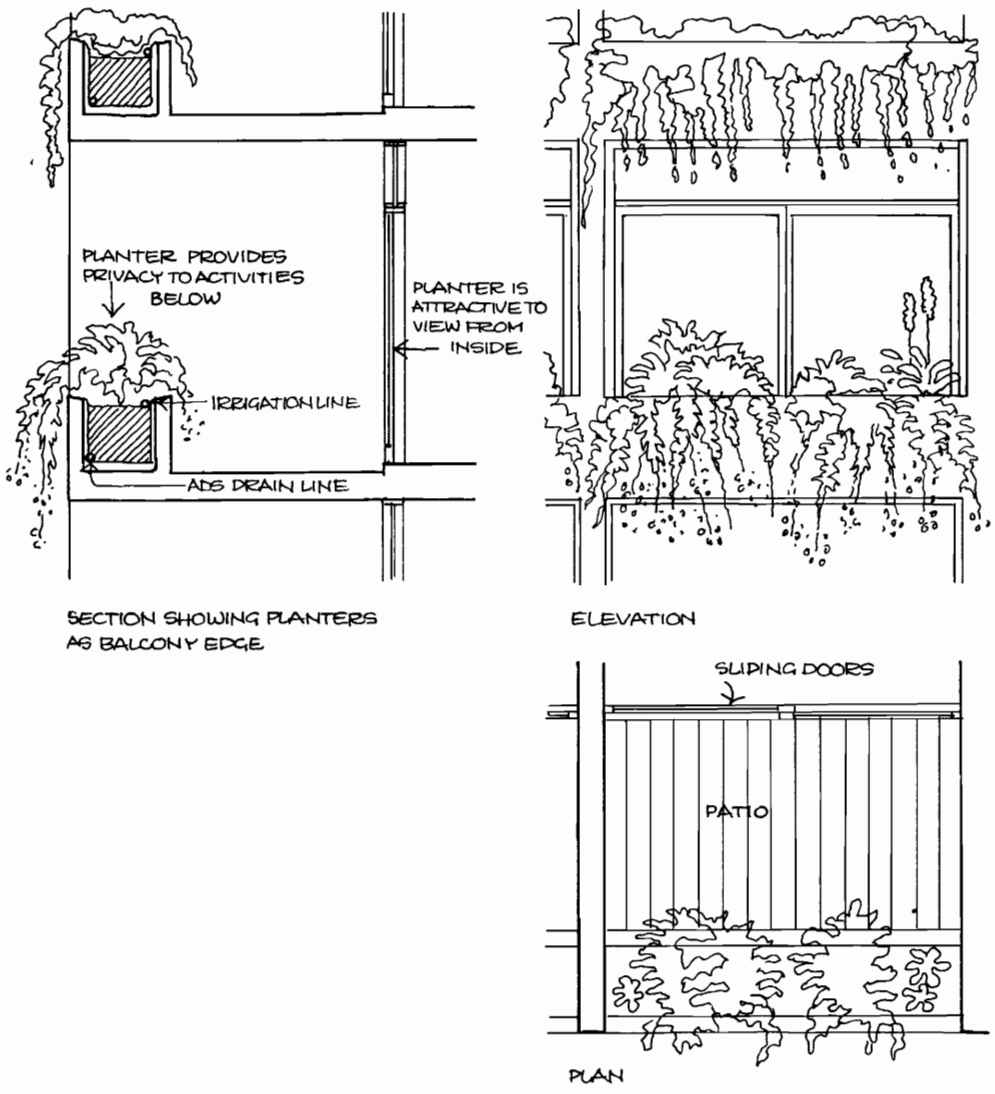
Groundcovers, shrubs, and vines

Timing

1-2 years

Maintenance

Moderate to high



PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: BALCONY EDGE PLANTER (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
4A3. Permit penetration of cool breezes.

Location

East, west or south wall.

Advantages

- Visual amenity.

Disadvantages

- Integral to initial structure.
- Relatively expensive.

PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: BRISE SOLEIL PLANTER

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
4A. Increase ventilation by cool breezes.
5A. Increase evaporative surfaces.

Suitable Plant Type

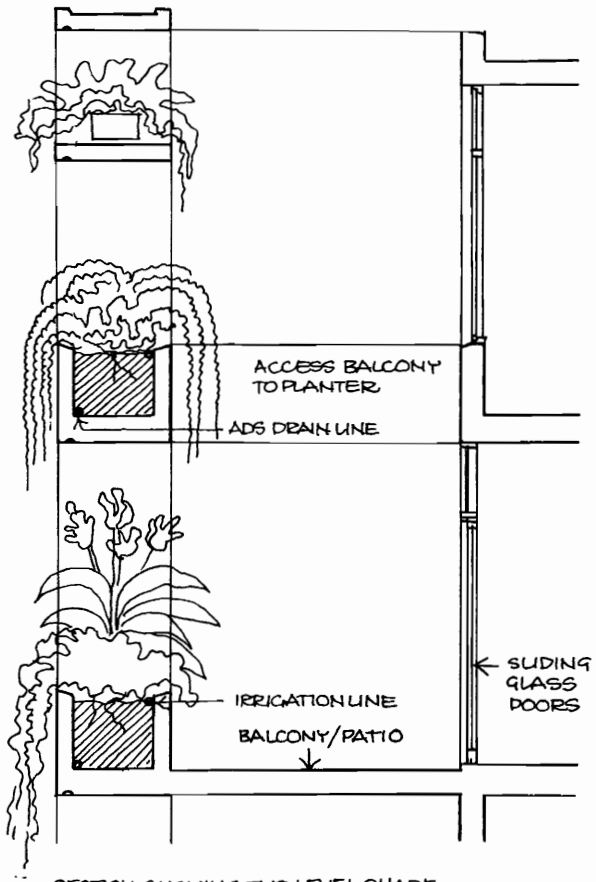
Groundcovers, shrubs, and vines

Timing

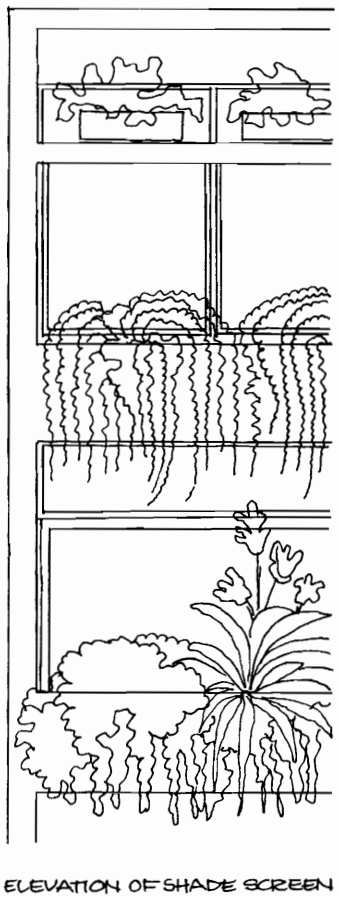
1-2 years

Maintenance

Moderate to high



SECTION SHOWING TWO LEVEL SHADE SCREEN WITH BUILT IN PLANTING BEDS



ELEVATION OF SHADE SCREEN

PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: BRISE SOLEIL PLANTER (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
4A3. Permit penetration of cool breezes.

Location

East, west or south wall.

Advantages

- Visual amenity

Disadvantages

- Expensive.
- Integral to initial structure.

PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: VINE-COVERED WALL

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
4A. Increase ventilation by cool breezes.
5A. Increase evaporative surfaces.
7A. Encourage conduction of heat from building walls and roof.

Suitable Plant Types

A) Vines with holdfasts and rootlets.
B) Twining or climbing vines.

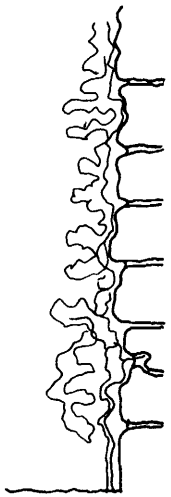
Timing

One story: 6 months - 5 years depending on growth rate of vine.

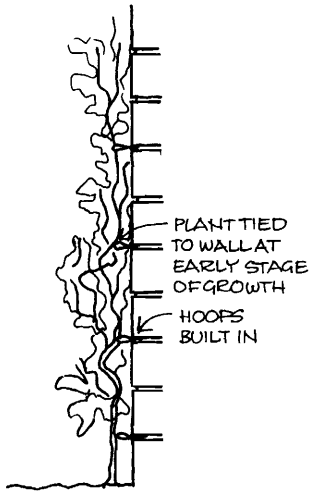
Maintenance

Both require yearly trimming to control growth pattern.

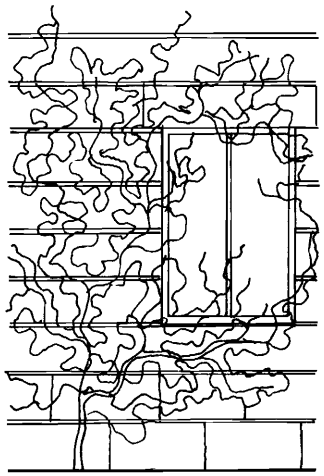
A) Low to moderate.
B) Moderate to high, vines must be tied to hoops.



A) CREEPERS ON ROUGH WALLS EG STONE — NATURAL HOLD



B) CREEPERS ON BRICK/BLOCK WALLS - HOOPS BUILT IN TO ALLOW TIES FOR TRAINING GROWTH UP WALLS



ELEVATION - CONTROL OF GROWTH PATTERN DIFFICULT

PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: VINE-COVERED WALL (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
4A3. Permit penetration of cool breezes.
7A2. Trap air cooled by evapo-transpiration next to building walls and roof.

Location

- South, east, or west walls.

Advantages

- Relatively inexpensive.
- Can be added to existing structure.

Disadvantages

- Difficult to remove.
- Yearly pruning required to control growth pattern.

PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: VINE-COVERED LATTICE

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
4A. Increase ventilation by cool breezes.
5A. Increase evaporative surfaces.
7A. Encourage conduction of heat from building walls and roof.

Suitable Plant Types

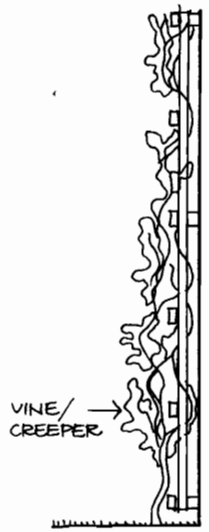
Twining or climbing vines; espaliered fruit trees, or large shrubs.

Timing

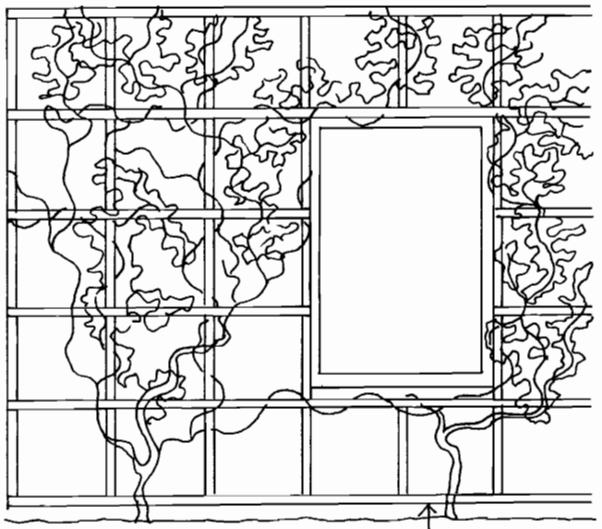
One story: 6 months to 5 years depending on growth rate of vine.

Maintenance

- Low.
- Requires yearly pruning at windows and doors.



SECTION OF LATTICE ATTATCHED DIRECTLY TO WALL



ELEVATION OF LATTICE SHOWING FRAMING OF WINDOW:

VARIABLE GRID POSSIBLE DEPENDING ON NEED FOR SHADE & PLANT TYPE

PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: VINE-COVERED LATTICE (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
4A3. Permit penetration of cool breezes.
7A2. Trap air cooled by evapo-transpiration next to building walls and roof.

Location

- South, east or west walls.

Advantages

- Relatively inexpensive.
- Can be added to existing structure.

Disadvantages

- Difficult to remove.
- Yearly pruning required to control growth pattern.

PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: VINE-COVERED CABLES

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
4A. Increase ventilation by cool breezes.
5A. Increase evaporative surfaces.
6A. Reduce heat storage in adjacent ground.

Suitable Plant Types

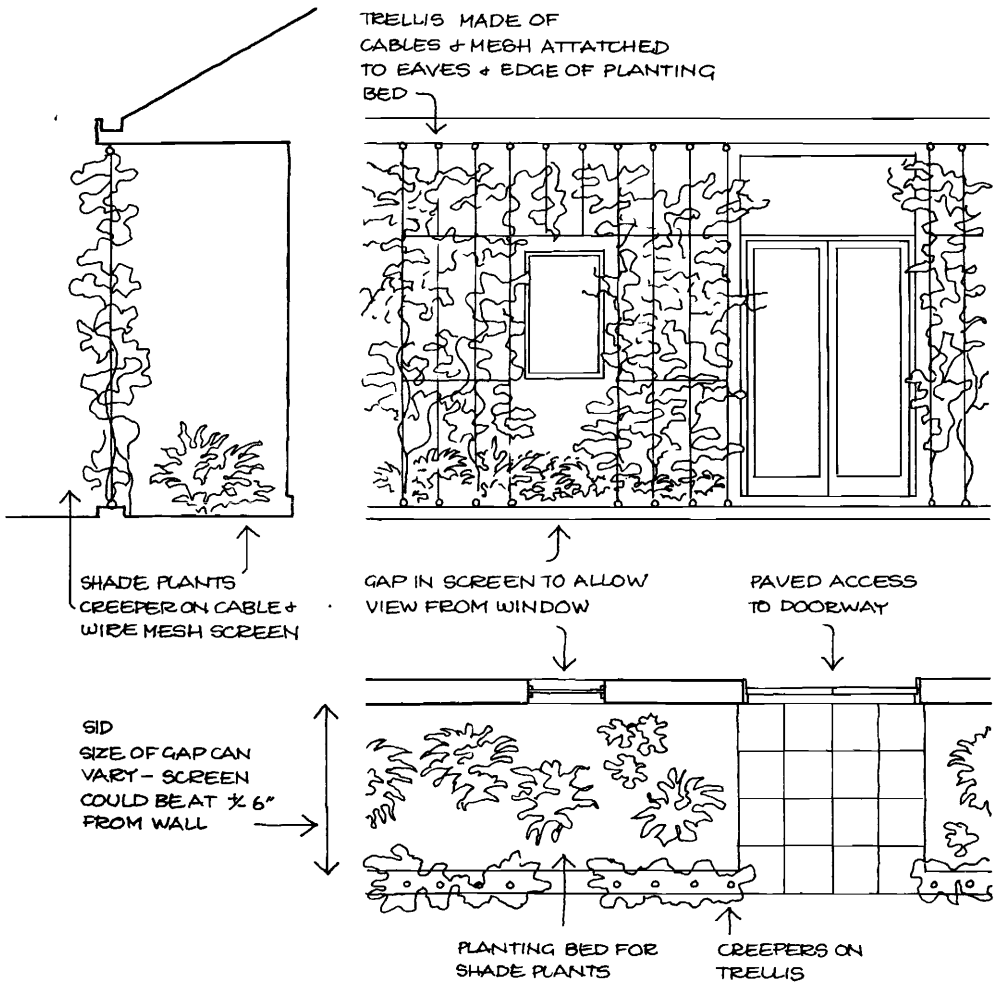
Climbing and twining vines.

Timing

One story: 6 months to 5 years depending on growth rate of vine.

Maintenance

Low.



PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: VINE-COVERED CABLES (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1C2. Reduce radiation reflected by surrounding ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
1D2. Reduce amount of radiation absorbed, stored and emitted by adjacent ground and walls.
4A3. Permit penetration of cool breezes.
6A1. Block incident radiation to ground surface.

Location

- East, west or south walls.

Advantages

- Relatively inexpensive.
- Independent of building structure, can be added to existing building.
- Can be easily removed and maintained.
- Creates shade garden.

PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: DETACHED LATTICE

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
5A. Increase evaporative surfaces.

Suitable Plant Types

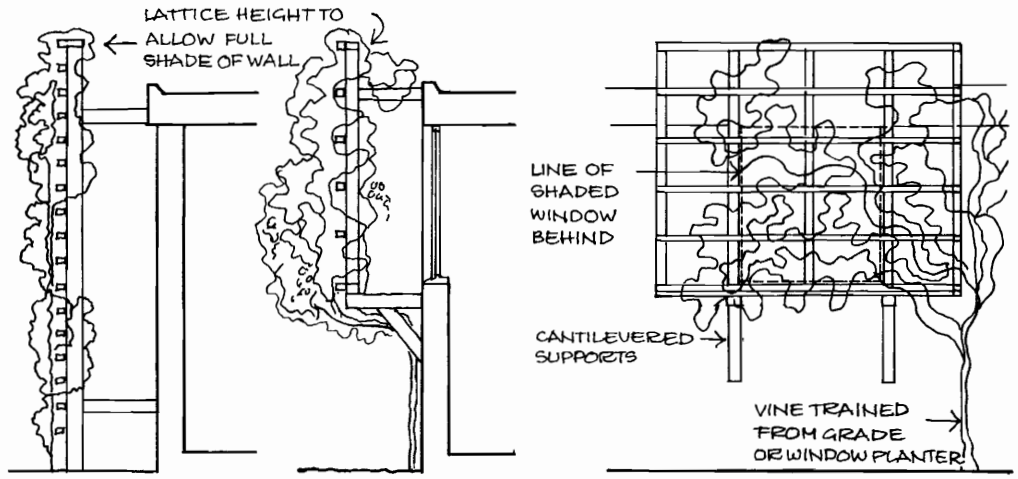
Climbing or twining vines.

Timing

One story: 6 months to 5 years depending on growth rate of vine.

Maintenance

Low.



A) FULL HEIGHT LATTICE POSITIONED TO ALLOW LIGHT TO WINDOWS & BREEZE ALONG BUILDING FACE

B) LATTICE AS WINDOW SHADE

ELEVATION OF PARTIAL LATTICE

PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: DETACHED LATTICE (continued)

Design Strategies

1A1. Block incident radiation
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.

Location

- East, west or south walls.

Advantages

- Relatively inexpensive.
- Independent of building structure, can be added to existing building.

PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: SLIDING WALL PLANTER

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
4A. Increase ventilation by cool breezes.
5A. Increase evaporative surfaces.
6A. Reduce heat storage in adjacent ground.

Suitable Plant Types

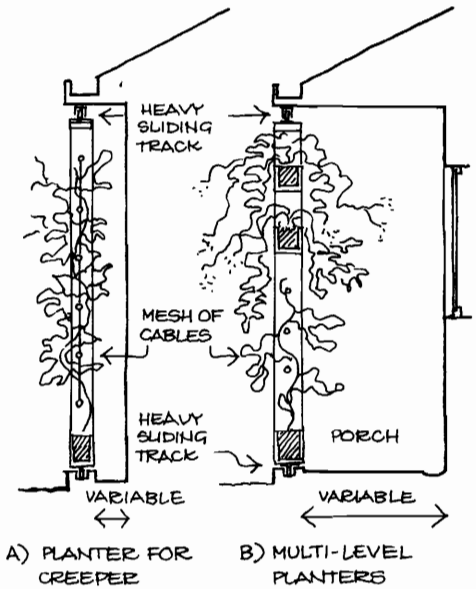
A) Climbing or twining vines.
B) Hanging groundcovers, climbing or twining vines.

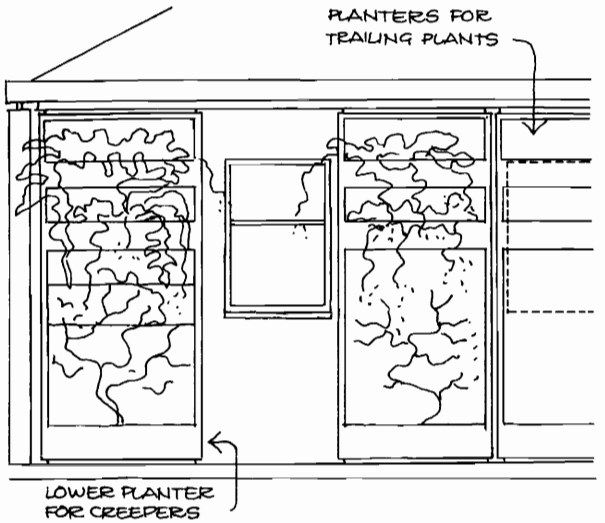
Timing

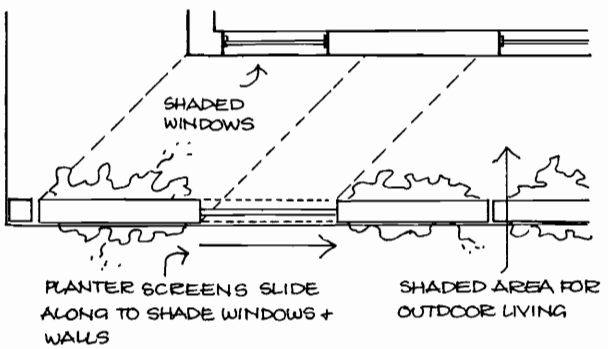
One story: 6 months to 5 years depending on growth rate of vine.

Maintenance

High, both require frequent watering and fertilization.







PASSIVE COOLING DESIGN APPLICATIONS

SCREEN: SLIDING WALL PLANTER (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1C2. Reduce radiation reflected by surrounding ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
1D2. Reduce amount of radiation absorbed, stored and emitted by adjacent ground and walls.
4A3. Permit penetration of cool breezes.
6A1. Block incident radiation to ground surface.

Location

East, west or south wall.

Advantages

- Flexible use, responds to changing needs for sun control.
- Independent of building structure, can be added to existing structure.

Disadvantages

- Expensive.
- Requires structural maintenance.

PASSIVE COOLING DESIGN APPLICATIONS

CANOPY: SLIDING WINDOW PLANTER

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
4A. Increase ventilation by cool breezes.
5A. Increase evaporative surfaces.

Suitable Plant Types

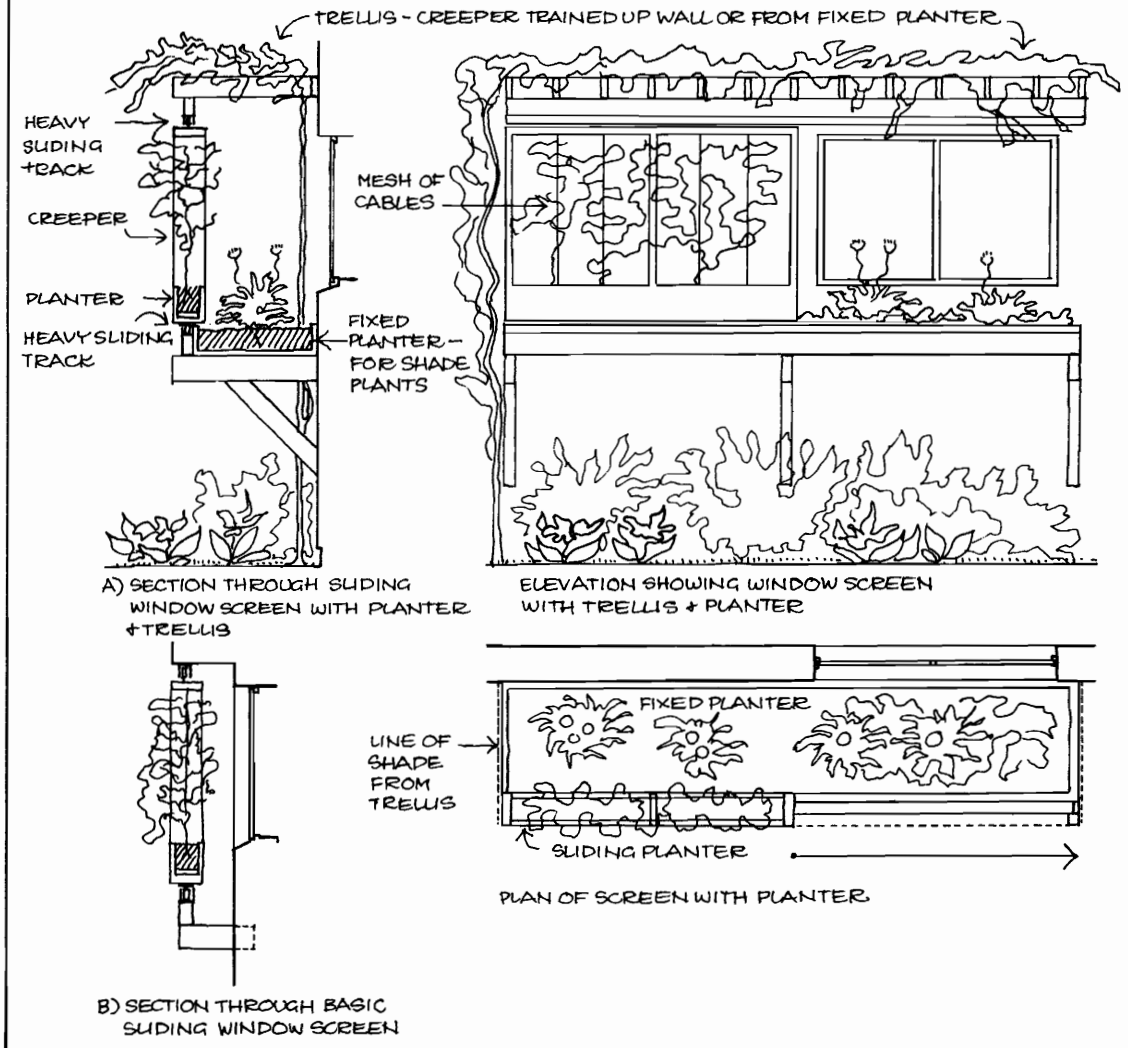
Climbing or twining vines.

Timing

Up to one year for window screen. Six months to 5 years for trellis, depending on growth rate of vine.

Maintenance

High, requires frequent watering and fertilization.



PASSIVE COOLING DESIGN APPLICATIONS

CANOPY: SLIDING WINDOW PLANTER (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
4A3. Permit penetration of cool breezes.

Location

East, south or west walls.

Advantages

- Flexible use, responds to changing needs for sun control.
- Multiple uses of plants.
- Independent of building structure, can be added to existing building.

Disadvantages

- Expensive.
- Requires structural maintenance.

PASSIVE COOLING DESIGN APPLICATIONS

SCREEN/COURT: HINGED PLANTER SCREEN

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
4A. Increase ventilation by cool breezes.
5A. Increase evaporative surfaces.
6A. Reduce heat storage in adjacent ground.
7A. Encourage conduction of heat from building walls and roof.

Suitable Plant Types

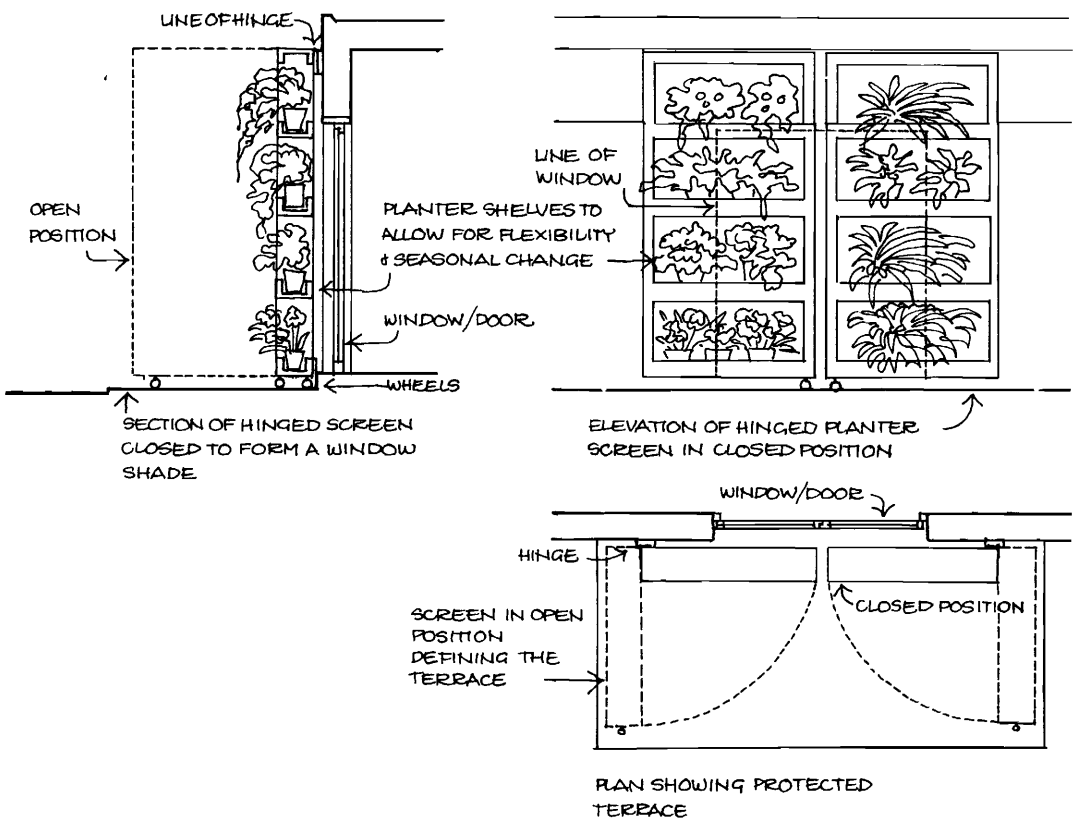
Annuals, perennials, low groundcovers.

Timing

Effective immediately.

Maintenance

Very high, many small pots require frequent watering and fertilization.



PASSIVE COOLING DESIGN APPLICATIONS

SCREEN/COURT: HINGED PLANTER SCREEN (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1C2. Reduce radiation reflected by surrounding ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
1D2. Reduce amount of radiation absorbed, stored and emitted by adjacent ground and walls.
4A3. Permit penetration of cool breezes.
6A1. Block incident radiation to ground surface.
7A2. Trap air cooled by evapo-transpiration next to building walls and roof.

Location

East, south or west walls.

Advantages

- Flexible use, responds to changing needs for sun control.
- Multiple uses of plants.
- Independent of building structure, can be added to existing building.

Disadvantages

- Expensive.
- Requires structural maintenance.
- Pots require frequent watering.

PASSIVE COOLING DESIGN APPLICATIONS

SCREEN/CANOPY: PIVOTING SCREEN/TRELLIS

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
4A. Increase ventilation by cool breezes.
5A. Increase evaporative surfaces.
6A. Reduce heat storage in adjacent ground.
7A. Encourage conduction of heat from building walls and roof.

Suitable Plant Types

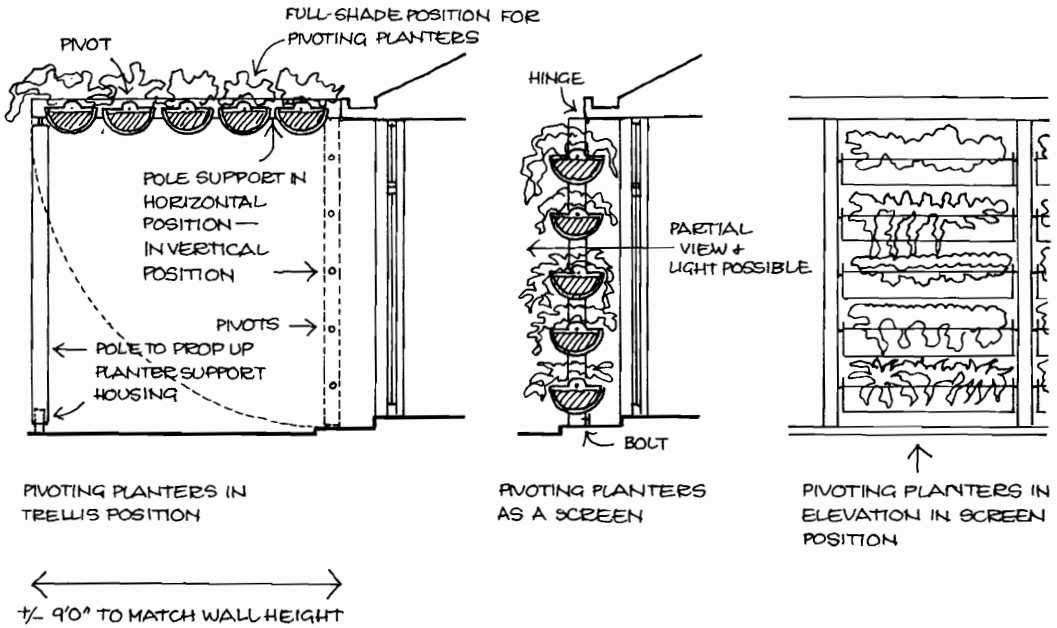
Prostrate groundcovers.

Timing

6 months to 1 year.

Maintenance

High, containers require frequent watering and fertilization.



PASSIVE COOLING DESIGN APPLICATIONS

SCREEN/CANOPY: PIVOTING SCREEN/TRELLIS (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1C2. Reduce radiation reflected by surrounding ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
1D2. Reduce amount of radiation absorbed, stored and emitted by adjacent ground and walls.
4A3. Permit penetration of cool breezes.
6A1. Block incident radiation to ground surface.
7A2. Trap air cooled by evapo-transpiration next to building walls and roof.

Location

East, south or west walls.

Advantages

- Flexible use, responds to changing needs for sun control.
- Multiple use of plants.
- Independent of building structure, can be added to existing building.

Disadvantages

- Expensive.
- Requires structural maintenance.
- Pots require frequent watering.

PASSIVE COOLING DESIGN APPLICATIONS

ROOF: ROOF LATTICE

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
5A. Increase evaporative surfaces.
7A. Encourage conduction of heat from building walls and roof.

Suitable Plant Types

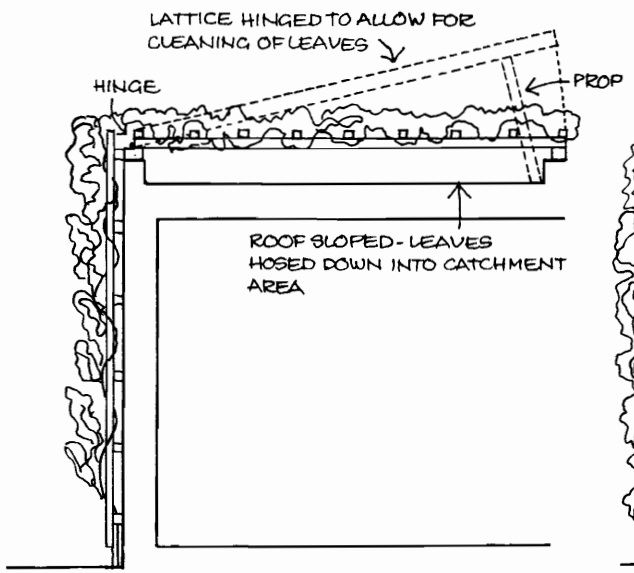
Twining and climbing vines.

Timing

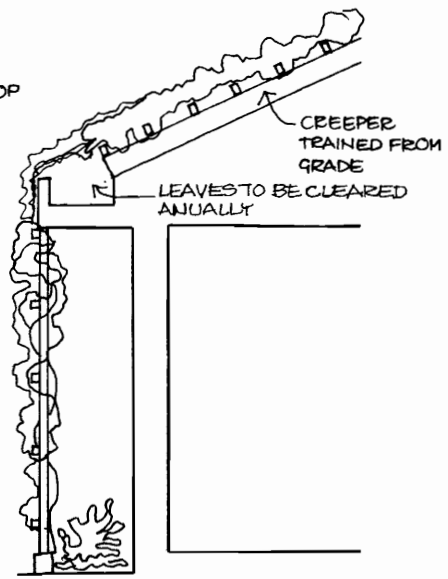
6 months to 5 years depending on growth rate of vine.

Maintenance

Low to moderate.



A) SECTION OF ROOF LATTICE FOR FLAT ROOF WITH HINGED PANELS TO ALLOW CLEANING



B) SECTION OF LATTICE ON SLOPED ROOF – TO BE HOSED DOWN OR SELF CLEANING WITH HEAVY RAINFALL – LARGE GUTTER FOR LEAVES

PASSIVE COOLING DESIGN APPLICATIONS

ROOF: ROOF LATTICE (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
7A2. Trap air cooled by evapo-transpiration next to building walls and roof.

Location

Roof.

Advantages

- Very cost-effective.
- Permits easy access for maintenance.
- Independent of building structure, can be added to existing building.

Disadvantages

- Requires removal of leaves.

PASSIVE COOLING DESIGN APPLICATIONS

ROOF: TURF ROOF

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
3A. Prevent infiltration of hot winds.
5A. Increase evaporative surfaces.
7A. Encourage conduction of heat from building walls and roof.

Suitable Plant Types

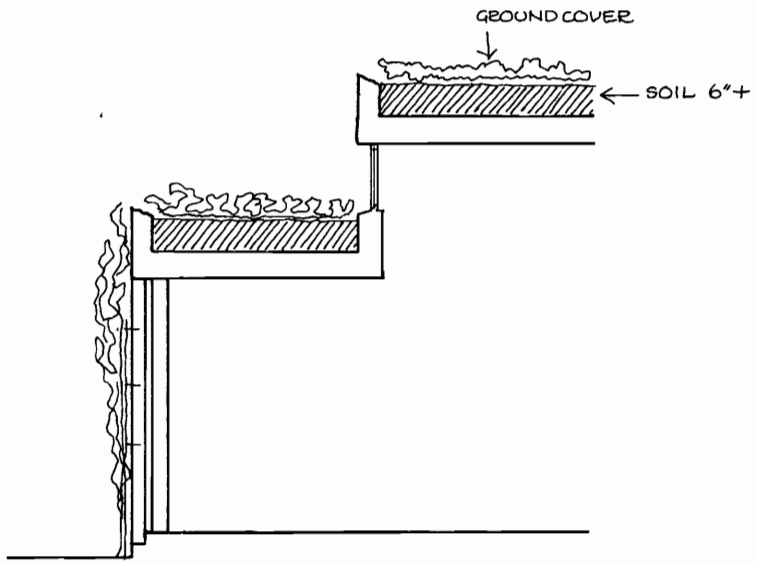
Grass, groundcovers, low shrubs, twining and climbing vines.

Timing

6 months to 2 years, depending on growth rate of plants selected.

Maintenance

Moderate.



SECTION SHOWING PLANTER ROOFS – SOIL ACTS AS INSULATOR

PASSIVE COOLING DESIGN APPLICATIONS

ROOF: TURF ROOF (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
3A3. Insulate building.
7A1. Expose building walls and roof to cool conductors.
7A2. Trap air cooled by evapo-transpiration next to building walls and roof.

Location

Roof.

Advantages

- Good insulation.

Disadvantages

- Expensive construction requires careful waterproofing.
- Difficult to maintain.
- Integral to building structure.

PASSIVE COOLING DESIGN APPLICATIONS

ROOF: ROOF GARDEN

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
3A. Prevent infiltration of hot winds.
5A. Increase evaporative surfaces.
7A. Encourage conduction of heat from building walls and roof.

Suitable Plant Types

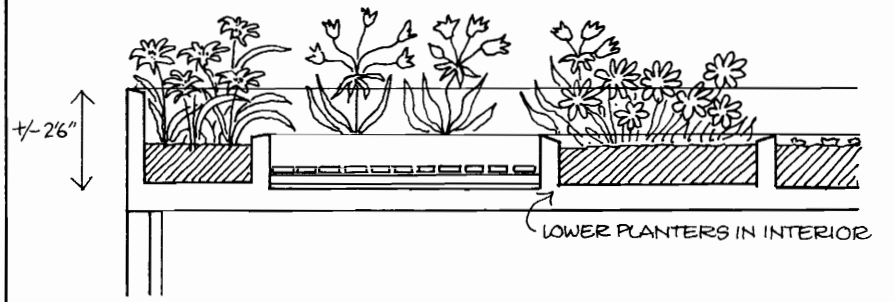
Groundcovers, low shrubs, annuals and perennials.

Timing

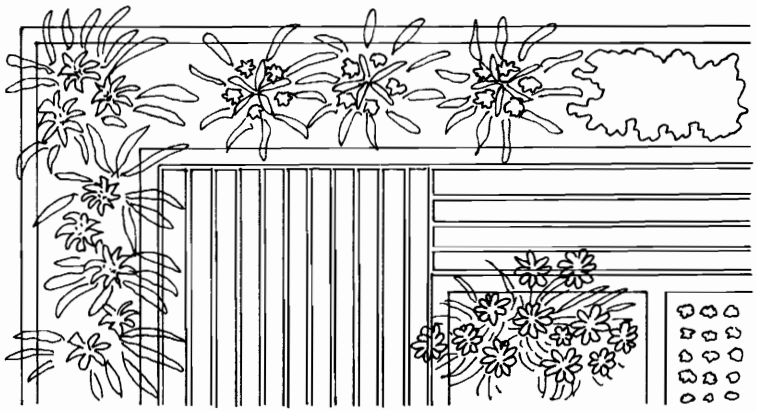
6 months to 1 year.

Maintenance

Moderate to high depending on plants selected.



SECTION SHOWING ALTERNATING PATTERN OF PLANTERS + WOODEN DECK



PLAN OF PORTION OF ROOF GARDEN

PASSIVE COOLING DESIGN APPLICATIONS

ROOF: ROOF GARDEN (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
3A3. Insulate building.
7A1. Expose building walls and roof to cool conductors.
7A2. Trap air cooled by evapo-transpiration next to building walls and roof.

Location

Roof.

Advantages

- Creates useful space on roof.

Disadvantages

- Expensive construction requires careful waterproofing.
- Difficult to maintain.
- Integral to building structure.

PASSIVE COOLING DESIGN APPLICATIONS

ROOF: TRELLISED ROOF GARDEN

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
3A. Prevent infiltration of hot winds.
4B. Replace hot air next to building wall and roof with cooler air.
5A. Increase evaporative surfaces.
7A. Encourage conduction of heat from building walls and roof.

Suitable Plant Types

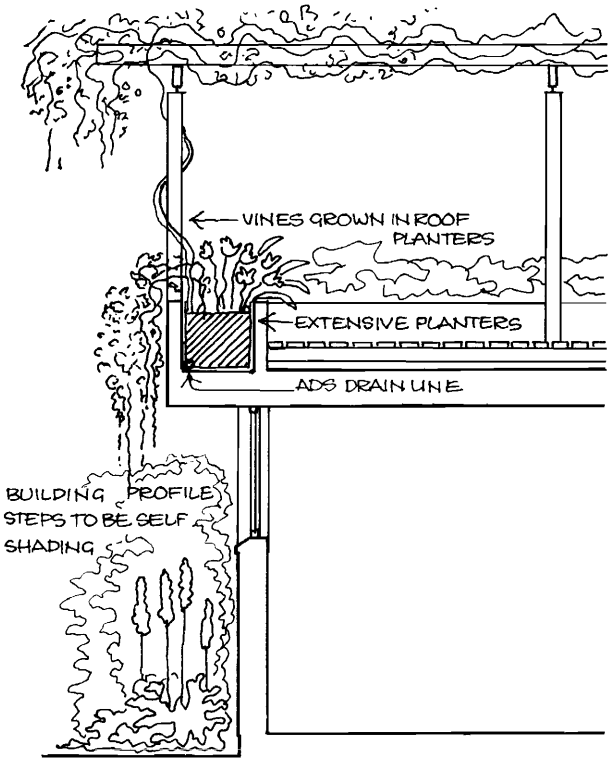
Climbing and twining vines, trailing groundcovers, shrubs at base of wall.

Timing

2 to 5 years.

Maintenance

Moderate to high.



SECTION SHOWING ROOF GARDEN SHADED BY VINE COVERED TRELLIS GIVING DOUBLE PROTECTION (PLAN SIMILAR TO 'ROOF GARDEN')

PASSIVE COOLING DESIGN APPLICATIONS

ROOF: TRELLISED ROOF GARDEN (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
3A3. Insulate building.
4B1. Direct winds over walls and roof.
7A1. Expose building walls and roof to cool conductors.
7A2. Trap air cooled by evapo-transpiration next to building walls and roof.

Location

Roof.

Advantages

- Creates useful, shaded space on roof.

Disadvantages

- Expensive construction requires careful waterproofing.
- Difficult to maintain.
- Integral to building structure.

PASSIVE COOLING DESIGN APPLICATIONS

ROOF: GLAZED PLANTER ROOF

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
3A. Prevent infiltration of hot winds.
5A. Increase evaporative surfaces.
7A. Encourage conduction of heat from building walls and roof.

Suitable Plant Types

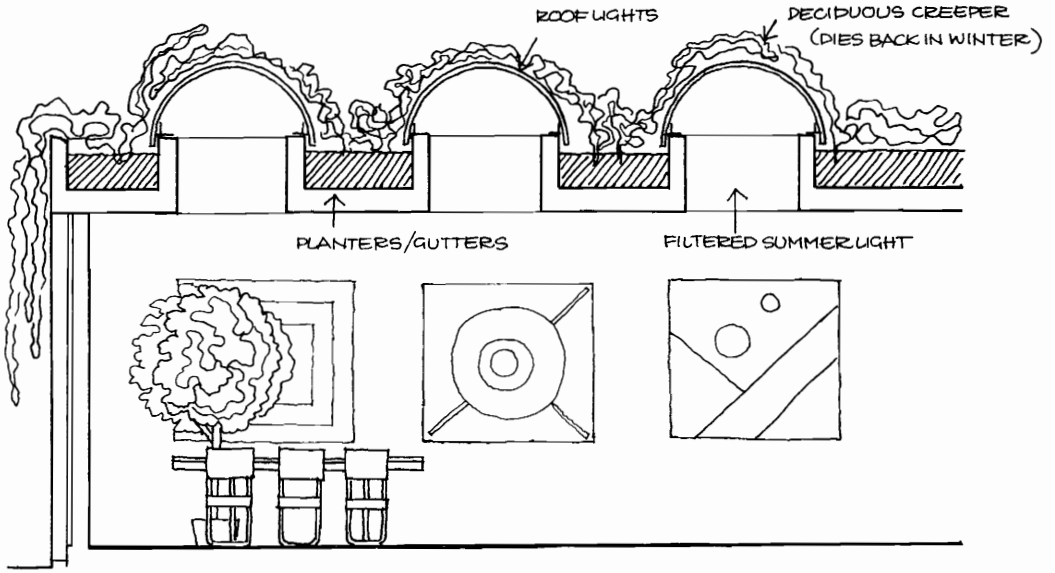
Deciduous vines and trailing ground-covers.

Timing

2 to 5 years.

Maintenance

Moderate.



SECTION THROUGH GLAZED PLANTER ROOF

PASSIVE COOLING DESIGN APPLICATIONS

ROOF: GLAZED PLANTER ROOF (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
3A3. Insulate building.
7A1. Expose building walls and roof to cool conductors.
7A2. Trap air cooled by evapo-transpiration next to building walls and roof.

Location

Roof.

Advantages

- Shade (filtered light) in summer, sun penetration in winter.
- Provides insulation.

Disadvantages

- Expensive construction requires careful water proofing.
- Difficult to maintain.
- Integral to building structure.

PASSIVE COOLING DESIGN APPLICATIONS

CANOPY: TREE CANOPY

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
3B. Prevent formation of hot winds.
4A. Increase ventilation by cool breezes.
5A. Increase evaporative surfaces.
5B. Increase rate of evaporation.
6A. Reduce heat storage in adjacent ground.

Suitable Plant Types

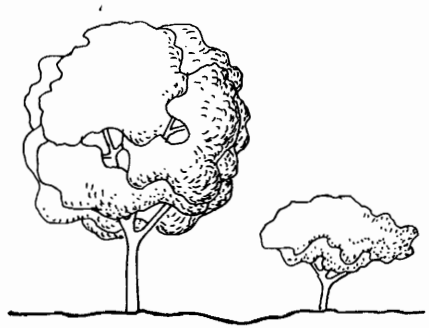
High-branching deciduous or evergreen trees.

Timing

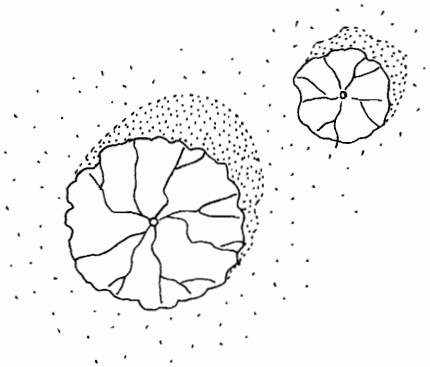
5 to 20 years (depending upon size of trees when planted and spacing between trees).

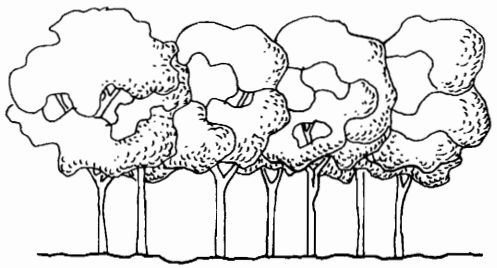
Maintenance

Low.

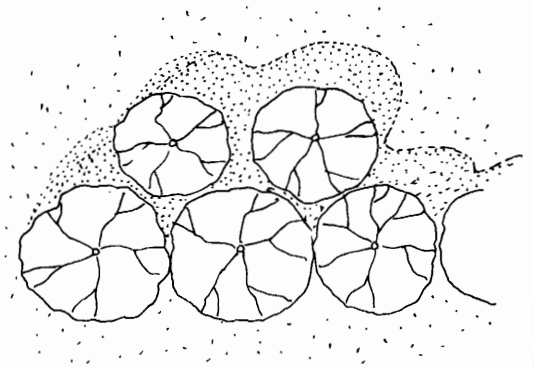


SINGLE TREE





GROVE OF TREES



PASSIVE COOLING DESIGN APPLICATIONS

CANOPY: TREE CANOPY (continued)

Design Objectives

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C2. Reduce radiation reflected by surrounding ground and walls.
1D2. Reduce amount of radiation absorbed, stored and emitted by adjacent ground and walls.
3B1. Reduce surface temperatures in prevailing wind directions.
4A1. Direct cool breezes toward building.
4A2. Increase wind speed.
4A3. Permit penetration of cool breezes.
5B2. Increase convection over evaporative surfaces.
6A1. Block incident radiation to ground surface.

Location

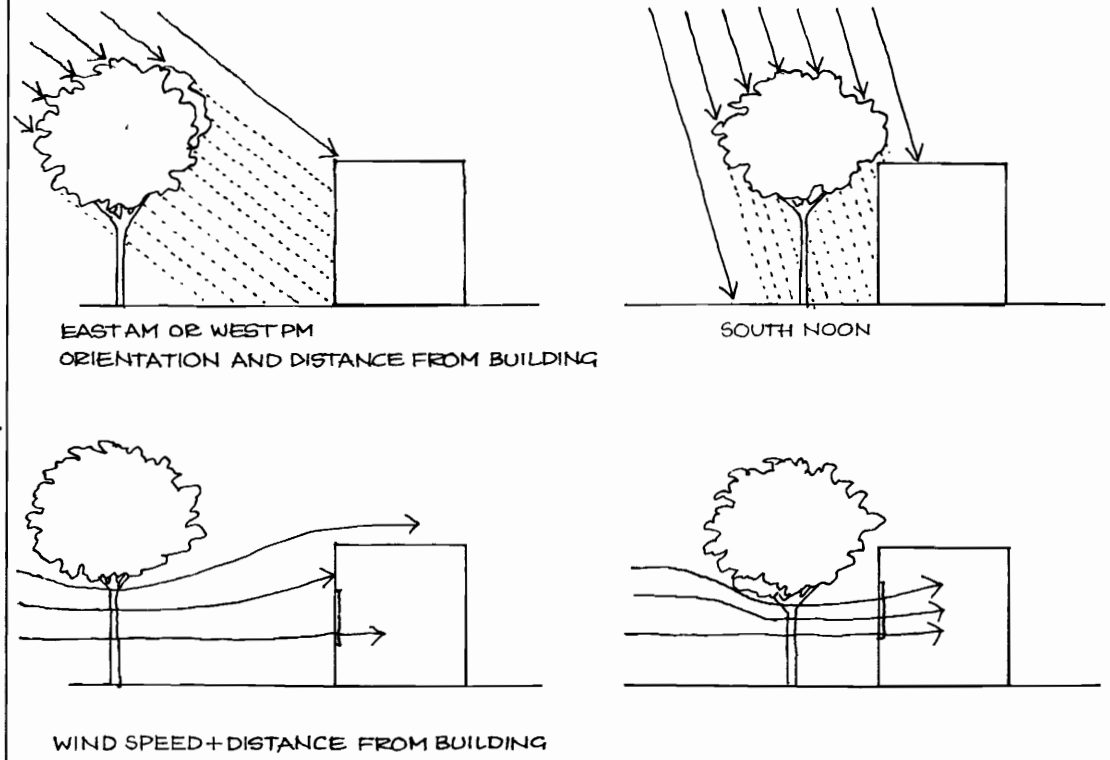
- Position to shade building walls, roof, and pavement around and upwind of building.
- Location depends upon orientation and solar angles (see diagram).
- Position close to window or door to increase ventilation (see diagram).

Advantages

- Can be added to existing building.
- May serve multiple functions.

Disadvantages

- Relatively long time to become effective.



PASSIVE COOLING DESIGN APPLICATIONS

CANOPY: FREESTANDING CANOPY

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
3B. Prevent formation of hot winds.
4A. Increase ventilation by cool breezes.
5A. Increase evaporative surfaces.
6A. Reduce heat storage in adjacent ground.

Suitable Plant Types

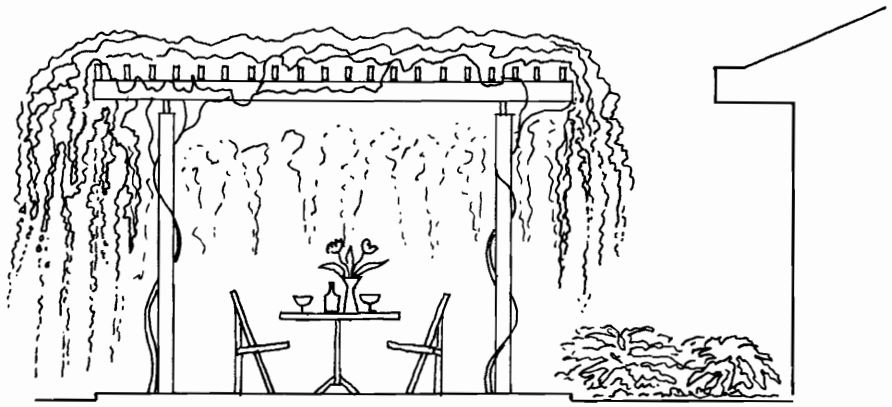
Climbing and twining vines.

Timing

6 months to 5 years depending on growth rate of vine.

Maintenance

Low (moderate until established).



SECTION THROUGH CREEPER COVERED 'ARBOR' CREEPERS TRAINED UP THE STRUCTURE FROM GRADE, OR FOR QUICK RESULTS PLANTERS BUILT INTO TRELLIS

PASSIVE COOLING DESIGN APPLICATIONS

CANOPY: FREESTANDING CANOPY (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1C2. Reduce radiation reflected by surrounding ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
1D2. Reduce amount of radiation absorbed, stored and emitted by adjacent ground and walls.
3B1. Reduce surface temperatures in prevailing wind directions.
4A3. Permit penetration of cool breezes.
6A1. Block incident radiation to ground surface.

Location

- To east, south or west of building.
- Over pavement around building (e.g., patio, sidewalks, parking).

Advantages

- Relatively inexpensive.
- Low maintenance.
- Provides shaded outdoor space.
- Independent of building structure.

PASSIVE COOLING DESIGN APPLICATIONS

CANOPY: ATTACHED TRELLIS

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
3B. Prevent formation of hot winds.
4A. Increase ventilation by cool breezes.
5A. Increase evaporative surfaces.
6A. Reduce heat storage in adjacent ground.

Suitable Plant Types

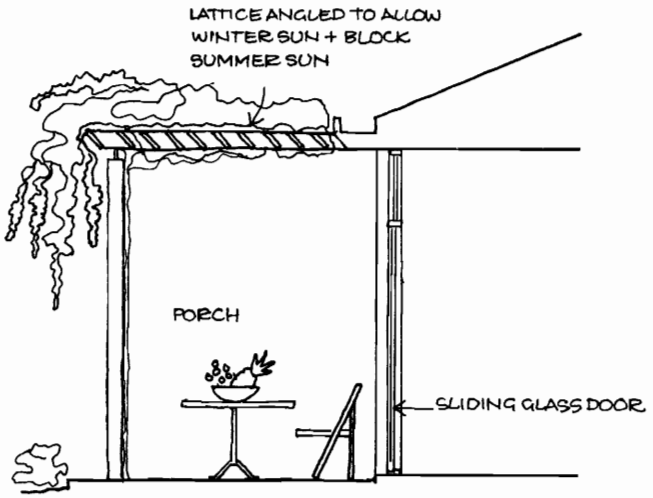
Climbing and twining vines.

Timing

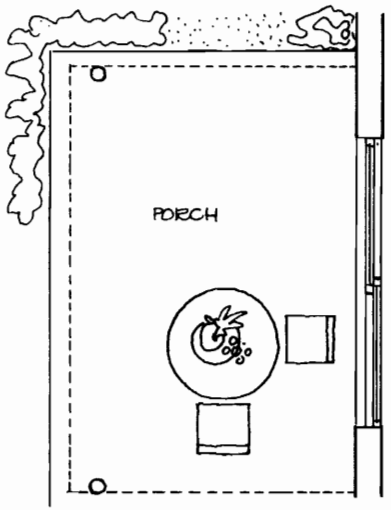
6 months to 5 years depending on growth rate of vine.

Maintenance

Low (moderate until established.



SECTION THROUGH TRELLIS AS EAVES EXTENSION



PLAN OF PORCH SHADED BY LATTICE

PASSIVE COOLING DESIGN APPLICATIONS

CANOPY: ATTACHED TRELLIS (continued)

Design Strategies

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1C2. Reduce radiation reflected by surrounding ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
1D2. Reduce amount of radiation absorbed, stored and emitted by adjacent ground and walls.
3B1. Reduce surface temperatures in prevailing wind directions.
4A1. Direct cool breezes toward building.
4A3. Permit penetration of cool breezes.
6A1. Block incident radiation to ground surface.

Location

- To east, south or west of building.
- Over pavement around building (e.g., patio, sidewalks, parking).

Advantages

- Relatively inexpensive.
- Low maintenance.
- Provides shaded outdoor space.
- Independent of building structure, can be added to existing building.

PASSIVE COOLING DESIGN APPLICATIONS

CANOPY: FIXED WINDOW SHADE WITH PLANTS

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
4A. Increase ventilation by cool breezes.
5A. Increase evaporative surfaces.

Suitable Plant Types

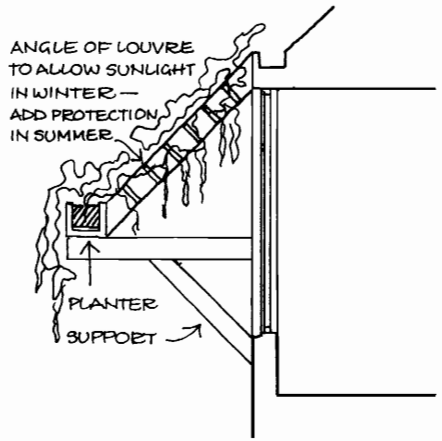
Climbing and twining vine or trailing groundcover.

Timing

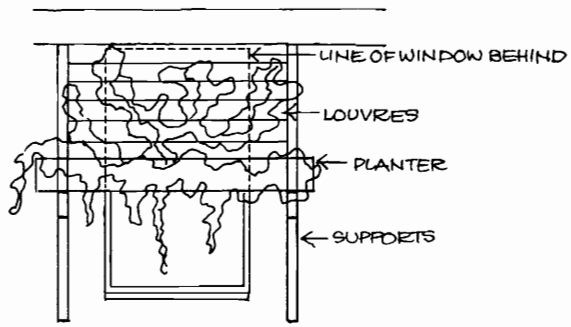
1 to 3 years.

Maintenance

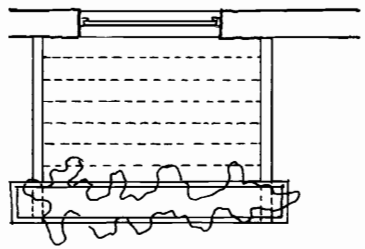
High, requires frequent watering and fertilization.



SECTION SHOWING PROJECTED ANGLED WINDOW SHADE



ELEVATION – PARTIAL CLEAR VIEW IS RETAINED



PLAN — AREA OF SHADE TO WINDOW SIZE DEPENDS ON CRITICAL SUN ANGLES

PASSIVE COOLING DESIGN APPLICATIONS

CANOPY: FIXED WINDOW SHADE

Design Objectives

1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
4A3. Permit penetration of cool breezes.

Location

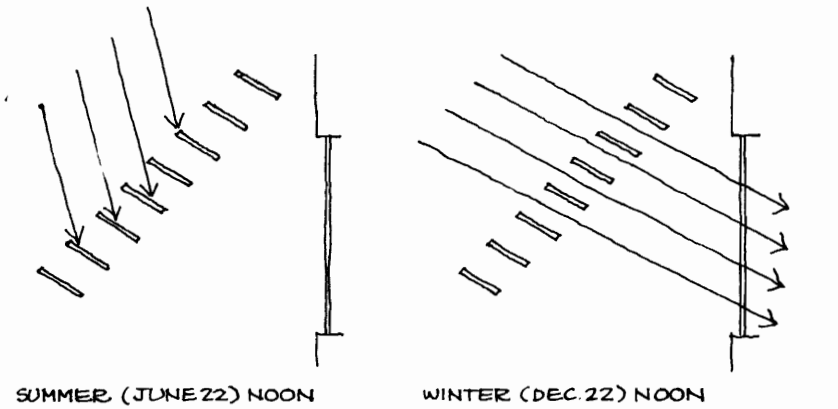
South window.

Advantages

- Relatively inexpensive.
- Independent of building structure, can be added to existing building.

Disadvantages

- Relatively high maintenance.



ANGLE OF TRELLIS AND SOLAR ANGLE FOR SOUTHERN WALL

PASSIVE COOLING DESIGN APPLICATIONS

FLOOR: PLANT FLOOR

Design Objectives

1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
3B. Prevent formation of hot winds.
5A. Increase evaporative surfaces.
6A. Reduce heat storage in adjacent ground.
6B. Cool adjacent ground.

Suitable Plant Types

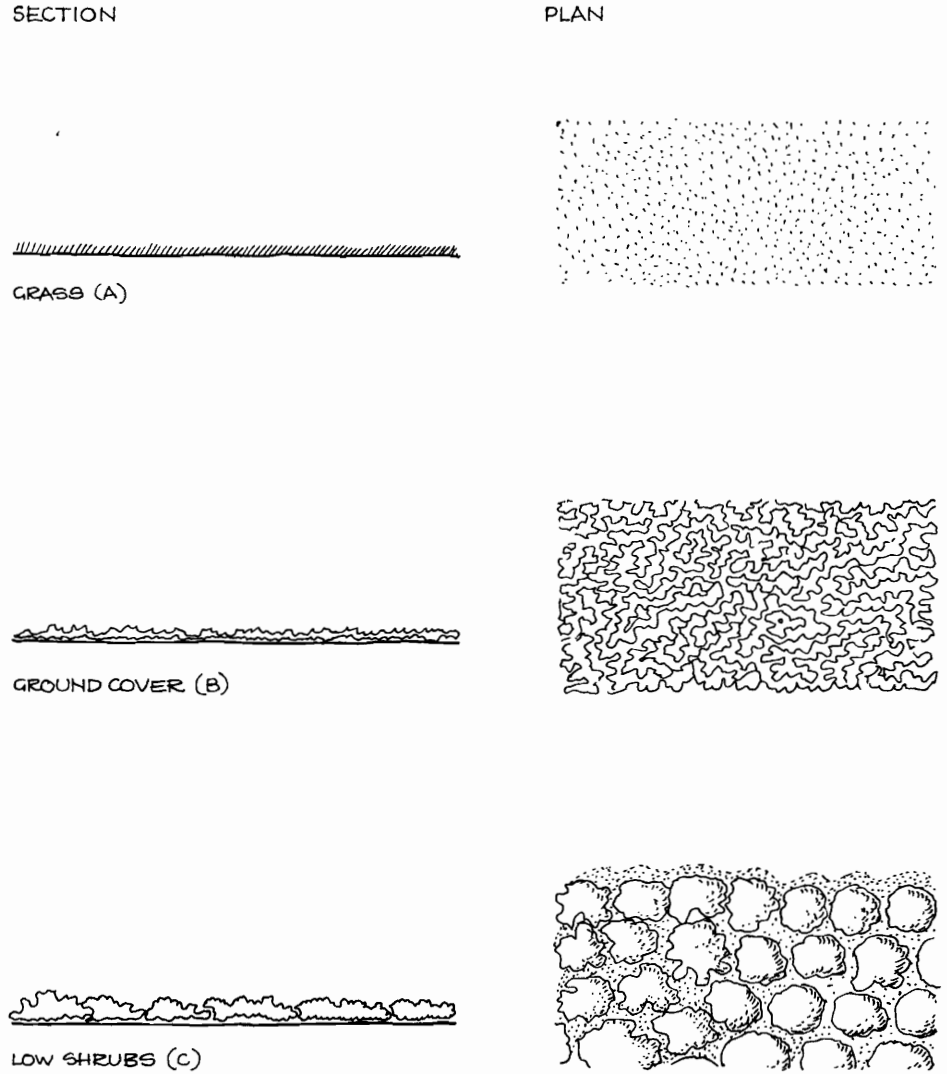
A) Grass.
B) Groundcovers.
C) Low shrubs.

Timing

A) 6 months.
B) 1 to 3 years.
C) 3 to 5 years.

Maintenance

Low.



PASSIVE COOLING DESIGN APPLICATIONS

FLOOR: PLANT FLOOR (continued)

Design Strategies

1C2. Reduce radiation reflected by adjacent ground and walls.
1D2. Reduce amount of radiation absorbed, stored and emitted by adjacent ground and walls.
3B1. Reduce surface temperatures in prevailing wind directions.
6A1. Block incident radiation to ground surface.
6B1. Trap air cooled by evapo-transpiration next to ground surface.

Location

Ground surrounding building.

Advantages

- Low maintenance.
- Inexpensive.
- Can be added around existing building.
- Achieves rapid effect.

Disadvantages

- Inappropriate in areas which receive intensive use, such as building access, parking, or service.

PASSIVE COOLING DESIGN APPLICATIONS

FLOOR: UNIT PAVERS IN GRASS

Design Objectives

1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
3B. Prevent formation of hot winds.
5A. Increase evaporative surfaces.
6A. Reduce heat storage in adjacent ground.
6B. Cool adjacent ground.

Suitable Plant Types

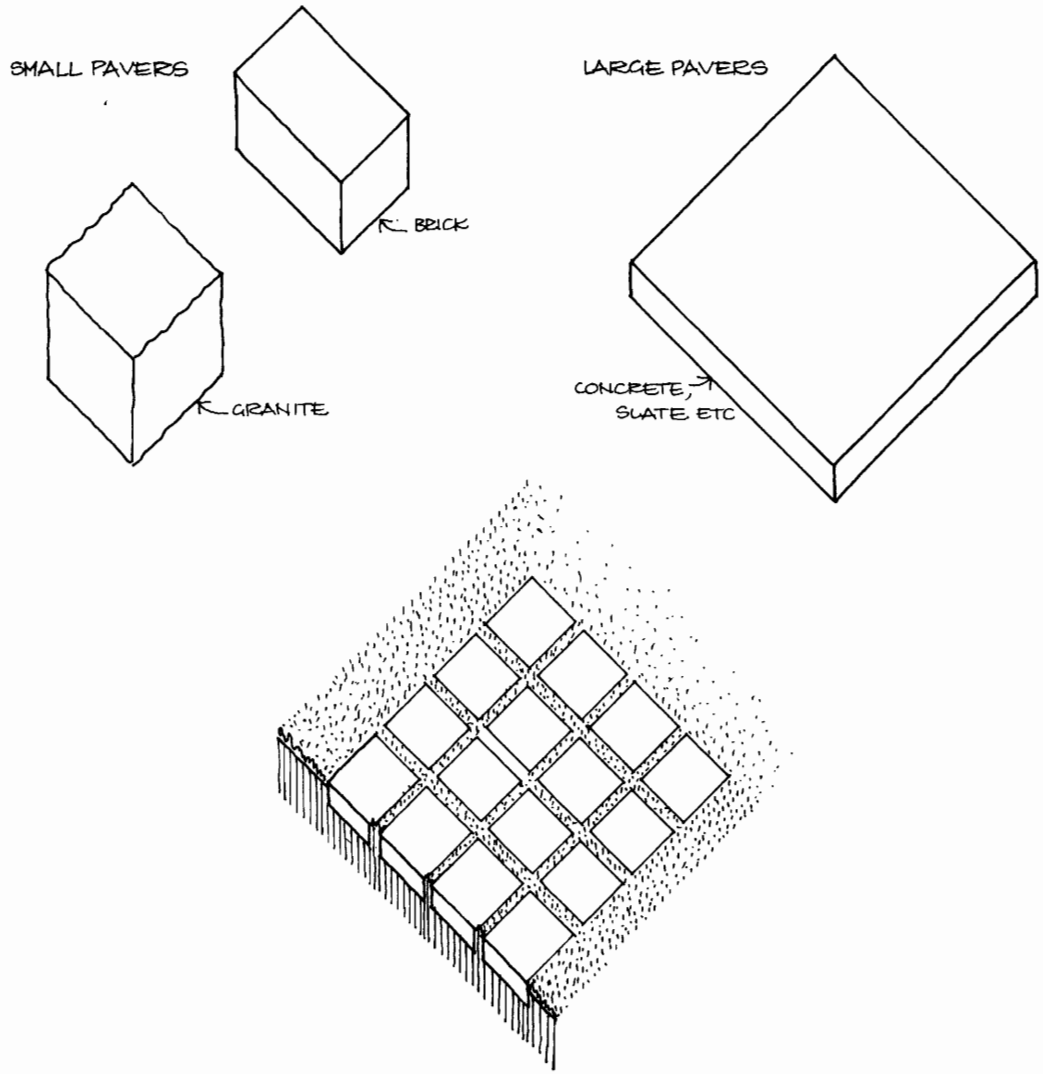
Prostrate groundcovers and grass.

Timing

6 months.

Maintenance

Moderate.



PASSIVE COOLING DESIGN APPLICATIONS

FLOOR: UNIT PAVERS IN GRASS (continued)

Design Strategies

1C2. Reduce radiation reflected by adjacent ground and walls.
1D2. Reduce amount of radiation absorbed, stored and emitted by adjacent ground and walls.
3B1. Reduce surface temperatures in prevailing wind directions.
6A1. Block incident radiation to ground surface.
6B1. Trap air cooled by evapo-transpiration next to ground surface.

Location

Ground surrounding building wherever pavement is necessary (e.g., walkways, patios, driveway)

Advantages

- Achieves immediate effect.
- Relatively low maintenance.
- Can be added around existing building.

Disadvantages

- More expensive than asphalt or poured concrete pavement.

PASSIVE COOLING DESIGN APPLICATIONS

FLOOR: GRASS PAVEMENT

Design Objectives

1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
3B. Prevent formation of hot winds.
5A. Increase evaporative surfaces.
6A. Reduce heat storage in adjacent ground.
6B. Cool adjacent ground.

Suitable Plant Types

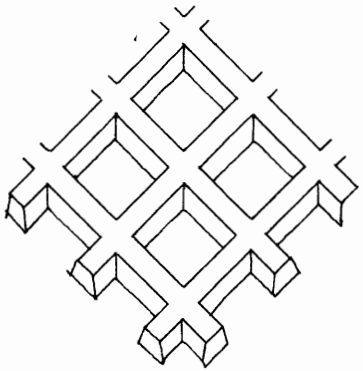
Grass.

Timing

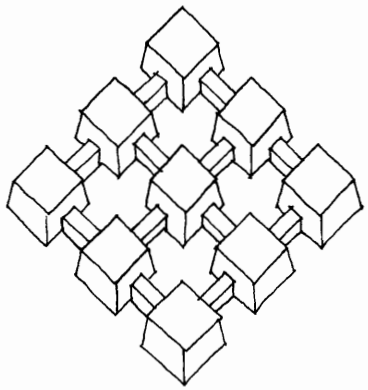
6 months.

Maintenance

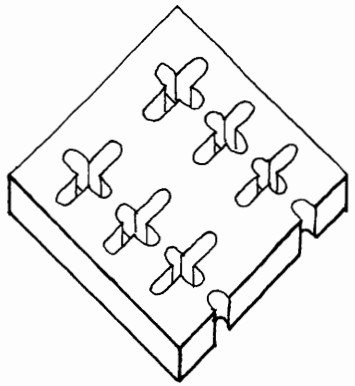
Moderate to high. Requires frequent watering and fertilization.



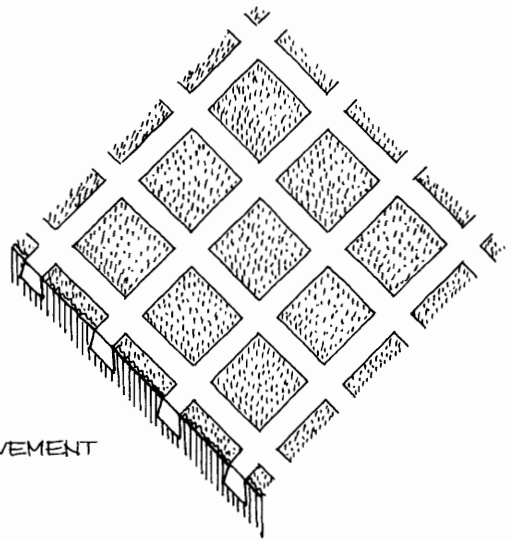
LATTICE



CASTELLATED



POURED-IN-PLACE



GRASS PAVEMENT

PASSIVE COOLING DESIGN APPLICATIONS

FLOOR: GRASS PAVEMENT (continued)

Design Strategies

1C2. Reduce radiation reflected by adjacent ground and walls.
1D2. Reduce amount of radiation absorbed, stored and emitted by adjacent ground and walls.
3B1. Reduce surface temperatures in prevailing wind directions.
6A1. Block incident radiation to ground surface.
6B1. Trap air cooled by evapo-transpiration next to ground surface.

Location

Ground surrounding building wherever pavement is necessary (e.g., walkways, patios, driveway, parking).

Advantages

- Can be used where extensive paving with good bearing surface is necessary.
- Achieves rapid effect.
- Can be added around existing building.

Disadvantages

- More expensive than asphalt or poured concrete.
- Requires moderate to high maintenance.

PASSIVE COOLING DESIGN APPLICATIONS

COURT: SHADE COURT/SUN POCKET

Design Objectives

1A. Avoid direct solar radiation.
1B. Avoid indirect solar radiation (diffuse and scattered radiation, back radiation from sky).
1C. Avoid reflected radiation.
1D. Avoid emitted radiation.
4A. Increase ventilation by cool breezes.
5A. Increase evaporative surfaces.
6A. Reduce heat storage in adjacent ground.

Suitable Plant Types

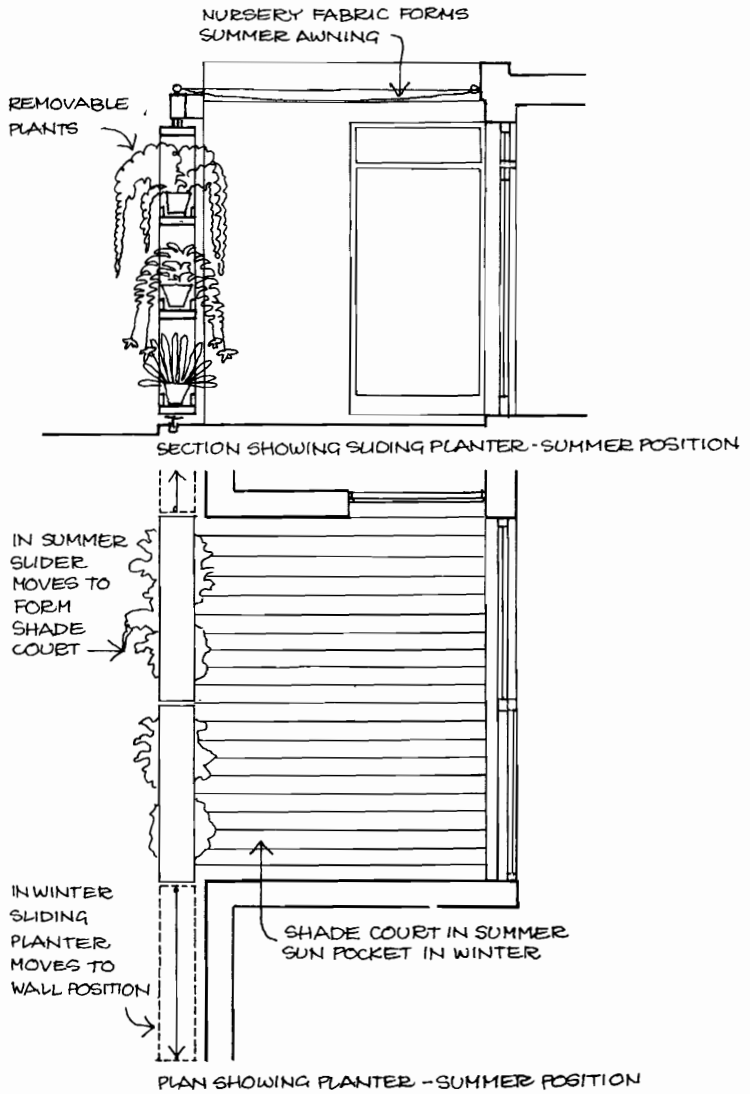
Groundcovers, annuals and perennials.

Timing

Effective immediately.

Maintenance

Very high, many small containers, requires frequent watering and fertilization.



PASSIVE COOLING DESIGN APPLICATIONS

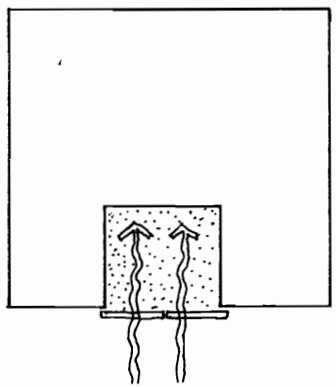
COURT: SHADE COURT/SUN POCKET

Design Objectives
1A1. Block incident radiation.
1B1. Block incident radiation from sky.
1C1. Block radiation reflected by adjacent ground and walls.
1C2. Reduce radiation reflected by surrounding ground and walls.
1D1. Block radiation emitted by adjacent ground and walls.
1D2. Reduce amount of radiation absorbed, stored and emitted by adjacent ground and walls.
4A3. Permit penetration of cool breezes.
6A1. Block incident radiation to ground surface.

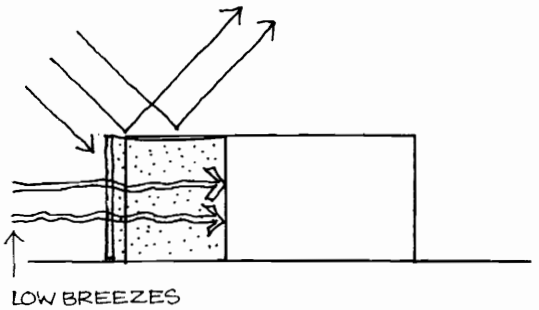
Location
South, southwest side of building.

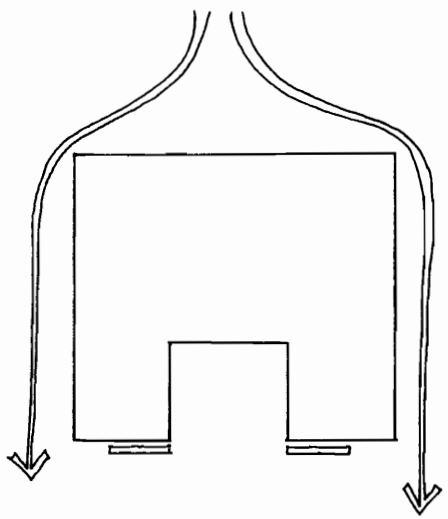
Advantages
- Adapts to seasonal use: provides shade in summer, sun in winter.
- Can be moved aside to permit ventilation at night.

Disadvantages
- Relatively expensive.
- Requires structural maintenance.

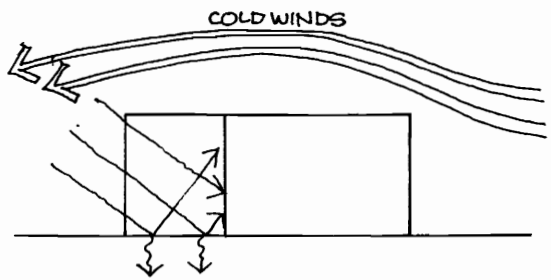


SUMMER SHADE COURT





FALL/SPRING SUNPOCKET



SELECTED PLANTS FOR PASSIVE COOLING

All plants are not suited to all passive cooling roles or situations. The selection of a particular plant species will depend upon the role it must play in passive cooling. The timing preferred for attainment of effective cooling, the intended location on or around the building, the level of maintenance provided, and the available budget are all important factors.

The list of plants assembled here is not comprehensive. The plants selected represent a range in terms of size, function, maintenance requirements, and cost. The list is limited to plants of the Eastern United States which grow in a temperate climate and are easily obtainable in nurseries:

— Large Deciduous Trees: Acer rubrum, Fraxinus pennsylvanica lanceolata, Liquidambar styraciflua, Liriodendron tulipifera, Platanus acerifolia, Populus nigra italica, Quercus borealis (rubra), Quercus phellos, Tilia cordata.

— Large Evergreen Trees: Magnolia grandiflora, Pinus nigra, Pinus strobus, Tsuga canadensis.

— Small Deciduous Trees: Acer palmatum, Cornus florida, Crataegus phaenopyrum (cordata), Lagerstromeia indica, Malus floribunda.

— Deciduous and Semi-Evergreen Shrubs: Abelia grandiflora, Euonymous alatus, Ligustrum ovalifolium, Spiraea van houttei.

— Evergreen Shrubs: Berberis julianae, Ilex crenata, Ligustrum lucidum, Taxus cuspidata, Thuja occidentalis.

— Vines: Campsis radicans, Celastrus scandens, Clemantis paniculata, Euonymous fortunei coloratus, Gelsemium sempervirens, Hedera helix, Hydrangea anomala petiolaris, Lonicera japonica halliana, Parthenocissus tricuspidata, Pueraria lobata, Wisteria floribunda.

— Groundcovers: Ajuga reptans, Cotoneaster dammeri, Liriope muscari, Juniperus horizontalis, Pachysandra terminalis, Rosa wichuraiana, Vinca minor.

Each plant's characteristics, requirements, and approximate cost are outlined in this section. Certain attributes--form, shade density, size, seasonal leafout and leafdrop--determine a plant's effectiveness for cooling. Others affect the time required for a species to achieve its full cooling affect and the necessary maintenance. A plant's requirements--light, soil texture, minimum soil depth, water, nutrients, container tolerance--determine suitable locations.

Form: The form of a plant influences the shape and pattern of its shadow and where it can be planted. For example, columnar trees cast a relatively small, linear shadow unless closely planted in rows. However, they can be planted close to building walls and are useful in narrow spaces.

Pyramidal trees cast a shadow which is broad near the base of the tree and narrow at its tip. Many tree species are pyramidal when young and spreading when mature.

Shade Density: Shade density determines how much sunlight passes through the leaves. Plants with light shade density usually have small leaves or a coarse branching pattern which allow considerable sunlight to penetrate. Plants which cast dense shade permit little or no direct sunlight within the shadow cast by the canopy.

Growth Rate: Rate of growth is a function of climate and growing conditions, as well as plant type. The estimates here assume adequate light, moisture, soil, and nutrients. Similar plant types are compared for their relative growth rates: very rapid, rapid, moderate, slow. Different plant types--trees, shrubs, vines groundcovers--grow at different rates. Six to eight feet per year is a rapid growth rate for a tree, whereas a vine may grow 20 feet in one year. Rapidly-growing plants can become maintenance problems when they outgrow their location. They have a shorter lifespan, are often weak-wooded and more susceptable to insect problems. However, they provide shade much faster than plants which grow more slowly. Rapidly-growing plants can be combined with plants of a moderate or slow growth rate to provide both short- and long-term effect.

Size at Five Years: The size estimate here assumes good growing conditions and is based on the typical size for residential plantings. Assume an initial size of 1½-2" caliper (10-12' high) for large trees, 4-6' high for small trees. For shrubs, assume an initial size of 18-24". Assume that vines are 1-gallon container or 2-year-old root stock. For groundcovers, assume 1-year stock cutting in 2¼" pots planted 8-15" on center.

Size at Maturity is an approximate eventual size for plants which have good growing conditions. Growth can be severely limited or even stopped at the original planted size in poor conditions (e.g., compacted soil, waterlogged or droughty soils, or when subjected to vandalism, root disturbance, damage from salt, oil, or chemicals).

Seasonal Leafout and Leafdrop: Some deciduous plant species leaf out earlier and lose their leaves later than others. Timing also depends on the region. Northern areas have early winters and late springs. Some plants which are evergreen in warmer, southern regions become semi-evergreen or deciduous at their northern limit for hardiness.

Light Requirements determine the amount of sunlight needed for good growth. Plants will often tolerate wider extremes if they are acclimated gradually. Plants requiring full sun do not tolerate shading by buildings or other plants. These plants thrive in midday and afternoon sunlight. Plants requiring partial shade can grow where they are exposed to morning or late afternoon sun or in the shade of plants with a medium to light shade density. Shade-loving plants do not tolerate midday sun.

Soil Texture varies from coarse, sandy soils to fine silts and clays. A lightweight soil mix consisting of 1/3 fine sand and 2/3 fine peat moss was developed by the University of California. It is ideal for use in containers.

Minimum Soil Depth: Larger plants usually need deeper soil than smaller plants, for root support, water, and nutrients. Trees which grow in

riparian or wet zones usually have fibrous root systems and can tolerate shallower soils than trees with deep taproots. Size, growth rate, life span, and tolerance to insects and diseases will be reduced when plants are planted with minimum soil depth. Plants in shallow soils also require more irrigation, more fertilization and are more exposed to winter freezing and summer heat.

Water is among the most critical of environmental factors. Some plants prefer moist conditions. These include trees and shrubs from riparian or wet zones which tolerate seasonal flooding or high water tables. Few plants prefer constantly high water levels. Most plants of the Eastern United States require a moderate amount of water. Other plants will tolerate drought, but grow better when some water is available.

Nutrients: Plants vary in the soil pH and nutrients they require. Some plants will tolerate a range in soil pH; others prefer neutral, slightly acid, or acid soils.

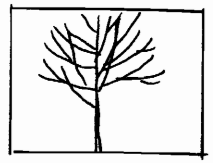
Container Tolerance: Plants in containers (window boxes, planters, roof decks) have limited life span and require more intensive maintenance than plants in the ground. Unless planted in very large containers, trees rarely do well for more than ten years. There are many shrubs, vines, and groundcovers, which have a very good tolerance for containers. Even these, however, may thrive for five to ten years, then decline. The major considerations are water and nutrient availability, drainage, and the amount of space for roots. Soil in containers dries out quickly, and plants in containers therefore require frequent watering or some form of irrigation. Even in large containers, plants may need two to three times the amount of water they would require if planted in the ground. Drainage is also critical. A flexible ADS drainline (4" in diameter) can be coupled to drains in large containers or on roofdecks and should be flushed out periodically to prevent clogging. Soil should be uniform in texture throughout to accomplish good drainage. Eventually, most plants, even shrubs and large vines, will become "root bound" when left in containers indefinitely.

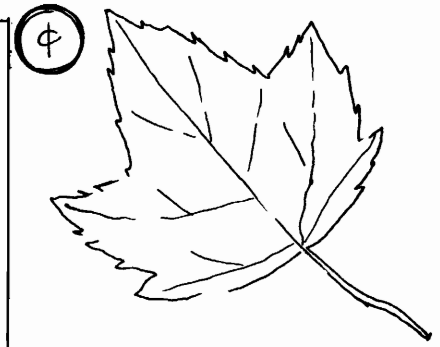
Maintenance required by different plants varies greatly, though most plants will survive with little care once they become established after the first two to three years. Only plants requiring very low to medium maintenance are included in the following pages. Many plants survive well with little maintenance, but respond better when given additional care. Plants grown in containers need more care than the same plants in the ground.

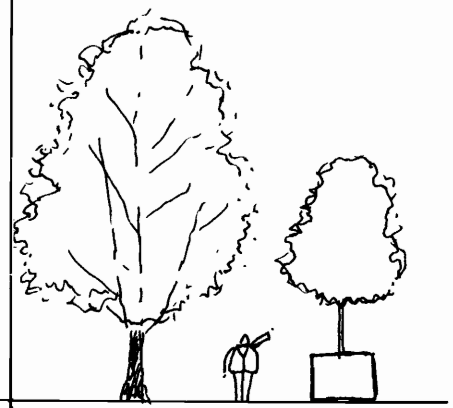
Cost: Estimated costs are based on the 1980 catalogues of four major nurseries in the Eastern United States. Installation cost assumes installation by a large nurseryman or a landscape contractor. This would include the cost of the plant material, soil, short-term maintenance, and a replacement guarantee.

TREE: LARGE DECIDUOUS

ACER RUBRUM (RED MAPLE)







Characteristics:

Form: Young - conical
Mature - upright, ovoid

Shade Density: Medium

Growth Rate: Moderate
18-24"/year

Size at 5 Years: 20-25'

Size at Maturity: Large - 60-80' height
40-60' spread

Seasonal Leafout: Mid-spring

Seasonal Leafdrop: Mid-fall

Requirements:

Light: Partial shade to full sun

Soil Texture: Coarse to fine

Minimum Soil Depth: 30-36"

Water: Moderate to moist

Nutrients: Tolerant--prefers acid soil

Container Tolerance: Good
4x6' min. diameter
10-15 year maximum

Maintenance: Medium

Cost:

Nursery Wholesale: 2" cal. - $60
5-6" cal. - $300

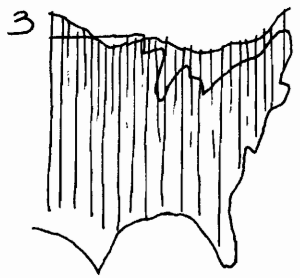
Installation Total: 2-3 x wholesale

References:

Hightshoe (1978)
Sunset (1979)
Hudak (1980)
Robinson (1960)

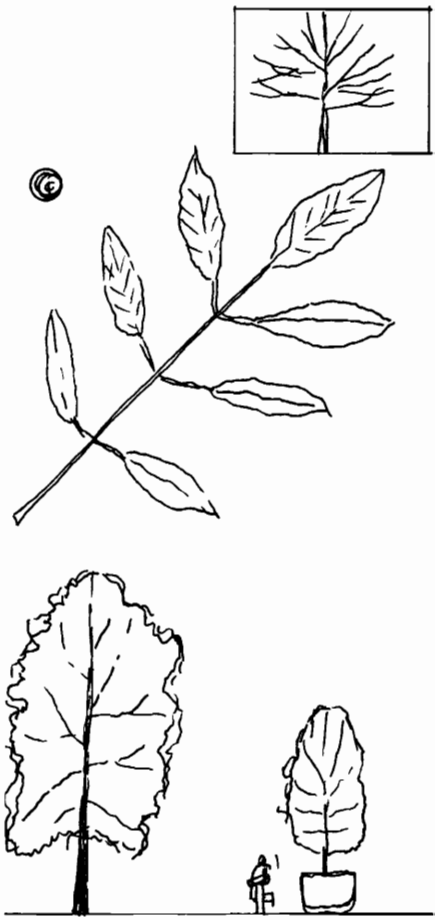
Notes:

- Shallow, fibrous roots
- Specimens recover slowly when moved
- Young whipstocks grow faster in 10 years than transplanted larger BB stock
- Diseases and insects frequent
- Sensitive to salts and lighting
- Intermediate sensitivity to pollution, drought, heat, and compacted soils
- Typical spacing: streets, 25-40' o.c.; cluster in groves, 15-20' o.c.



TREE: LARGE DECIDUOUS

FRAXINUS PENNSYLVANICA LANCEOLATA (GREEN ASH)



Characteristics:

Form: Irregular, ovoid to oblong

Shade Density: Medium to light

Growth Rate: Moderate to rapid
24-30"/year when young

Size at 5 Years: 25-30'

Size at Maturity: 50-75' high
35-50' spread

Seasonal Leafout: Late spring

Seasonal Leafdrop: Early fall

Requirements:

Light: Full sun to partial shade

Soil Texture: Coarse to medium

Minimum Soil Depth: 30 x 36"

Water: Drought-tolerant to moist

Nutrients: Slightly acid to neutral

Container Tolerance: Good for 10 years in 4'x6' container

Maintenance: Low to medium

Cost:

Nursery Wholesale: 2" cal. $70-75 BB
4" cal. $200-225 BB

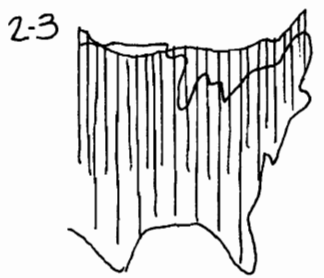
Installation Total: 2.5-3 x wholesale

References:

Hightshoe (1978)
Robinson (1960)

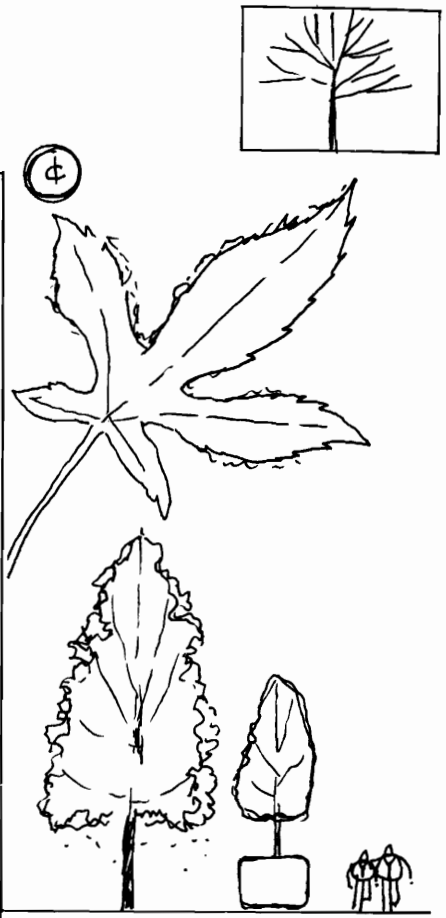
Notes:

- Typical spacing: 25-40' o.c.
- Shallow roots
- "Marshall's" cultivar widely grown in East and Midwest
- Tolerates urban situations well
- Insect problems with bores, scale, leaf minors
- Frequent ice problems (brittle)



TREE: LARGE DECIDUOUS

LIQUIDAMBAR STYRACIFLUA (SWEETGUM)



Characteristics:

Form: Young - upright, conical
Mature - ovoid

Shade Density: Medium to dense

Growth Rate: Slow to moderate, faster when young

Size at 5 Years: 25-30'

Size at Maturity: Large, 75'x50'

Seasonal Leafout: Mid-spring

Seasonal Leafdrop: Late fall

Requirements:

Light: Full sun
Intolerant of dense shade

Soil Texture: Coarse to fine

Minimum Soil Depth: 24-30"

Water: Moderate to moist; drought tolerant once established

Nutrients: Slightly acid
high pH--iron chlorosis

Container Tolerance: Good
10 year tolerance in 3'x5' container

Maintenance: Medium

Cost:

Nursery Wholesale: 2" cal. - $60-75
5-6" cal. - $325-375

Installation Total: 2.5-3 x wholesale

References:

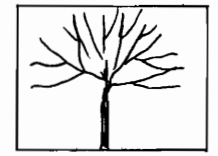
Hightshoe (1978)
Sunset (1979)
Wyman (1977)
Robinson (1960)

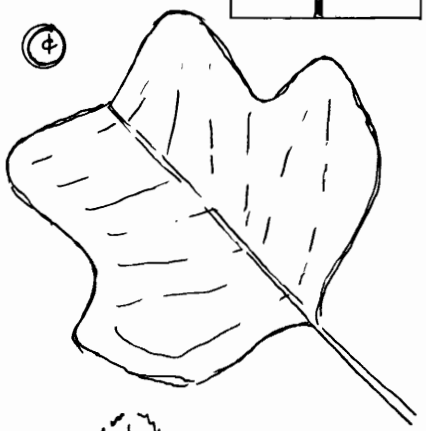
Notes:

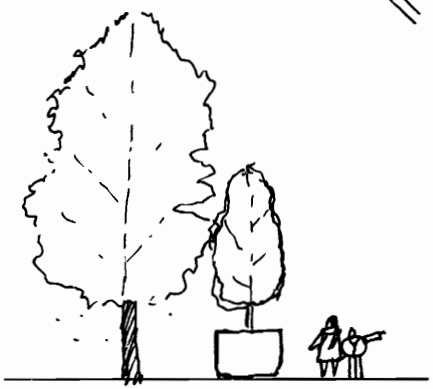
- Typical spacing: 25-40' o.c.; cluster in groves, 10' o.c.
- Recovers slowly when moved at large sizes; smaller whipstocks often grow faster
- Late fall growth often frost damaged
- Resists disease and insects
- Sensitive to pollution

TREE: LARGE DECIDUOUS

LIRIODENDRON TULIPIFERA (TULIP TREE, TULIP POPLAR)







Characteristics:

Form: Young - upright conical
Mature - broadly pyramical

Shade Density: Medium

Growth Rate: Young - rapid
Mature - moderate

Size at 5 Years: 25-30'

Size at Maturity: 100-150' height
50-75' spread

Seasonal Leafout: Mid-spring

Seasonal Leafdrop: Mid-fall

Requirements:

Light: Full sun to partial shade

Soil Texture: Mod. fine to medium

Minimum Soil Depth: 36-40"

Water: Moderate to moist

Nutrients: Acid to neutral

Container Tolerance: Poor
Very short-term only

Maintenance: Medium

Cost:

Nursery Wholesale: 2" cal. - $70-80 BB
4" cal. - $225-250 BB

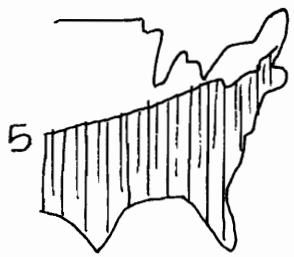
Installation Total: 2.5-3 x wholesale

References:

Hudak (1980)
Hightshoe (1978)
Robinson (1960)

Notes:

- Typical spacing: 30-50' o.c., dense clusters, 10-15' o.c.
- Difficult to transplant
- Problems with aphids and scale
- Most prized outside typical growth range



TREE: LARGE DECIDUOUS

PLATANUS ACERIFOLIA (LONDON PLANETREE)

Characteristics:

Form: Young - pyramidal
Mature - globular

Shade Density: Medium to dense

Growth Rate: Rapid
24-30"/year

Size at 5 Years: 30-35'

Size at Maturity: 100' x 75'

Seasonal Leafout: Late spring

Seasonal Leafdrop: mid-late fall

Requirements:

Light: Full sun to partial shade

Soil Texture: Coarse to fine

Minimum Soil Depth: 36-42"

Water: Drought-tolerant to moist

Nutrients: Neutral to acid
Low nutrient requirements

Container Tolerance: Fair/very large only
10-15 years
4x6' min. container

Maintenance: Low

Cost:

Nursery Wholesale: 2" cal. $60-70 BB
4" cal. $185-200 BB
6" cal. $300-325 BB

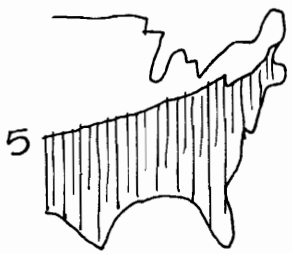
Installation Total: 2.5-3 x wholesale

References:

Hightshoe (1978)
Robinson (1960)
Hudak (1980)

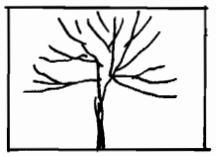
Notes:

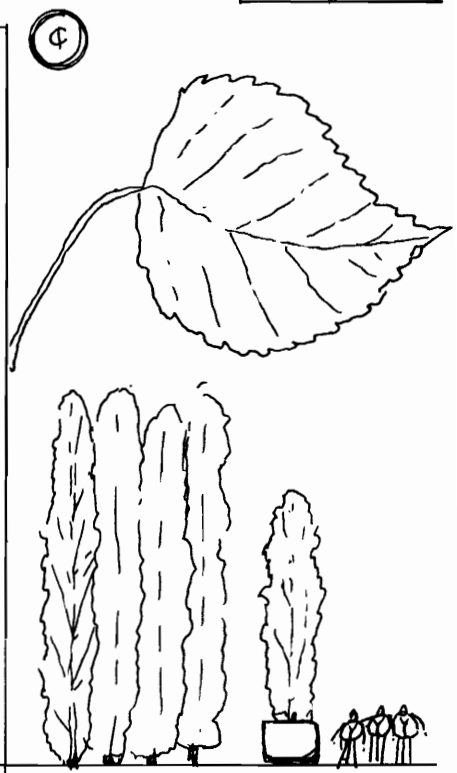
- Typical spacing: 25-40' o.c.
- Cultivar - "Bloodgood" limited availability, but with anthracnose resistance
- Alt. - Platanus occidentalis (zone 4)
- Among most widely planted trees in downtowns around country.
- Can be pollarded to limit size.



TREE: LARGE DECIDUOUS

POPULUS NIGRA ITALICA (LOMBARDY POPLAR)





Characteristics:

Form:	Upright, columnar
Shade Density:	Medium
Growth Rate:	Very rapid
Size at 5 Years:	30-40'
Size at Maturity:	60-80' high x 10-15' wide
Seasonal Leafout:	Mid-spring
Seasonal Leafdrop:	Mid-fall

Requirements:

Light:	Full sun or partial shade
Soil Texture:	Coarse to medium
Minimum Soil Depth:	30-36" depth
Water:	Moist preferred, but will tolerate moderate
Nutrients:	Neutral to acid Wide tolerance
Container Tolerance:	Short-term only
Maintenance:	High

Cost:

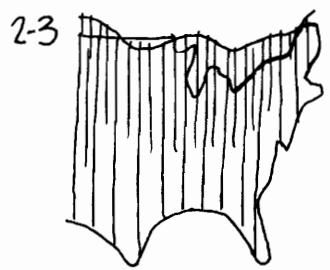
Nursery Wholesale:	2" cal. BB $60-70 4" cal. BB $135-140
Installation Total:	2.5 x wholesale

References:

Hudak (1980)
Robinson (1960)
Sunset (1979)

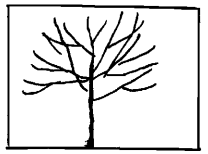
Notes:

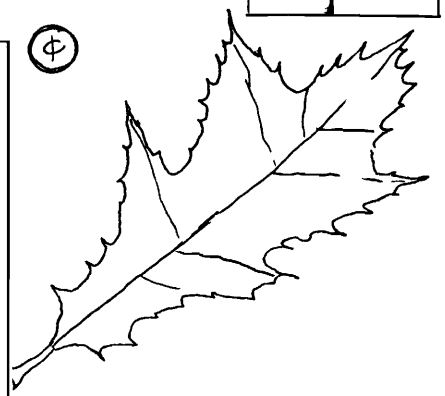
- Typical spacing: 10-15' o.c.
- Very short lifespan, ideal interim plant
- Leaf litter, breakage, and cankers are typical
- Insect problems
- Good urban tolerance
- Very distinctive form

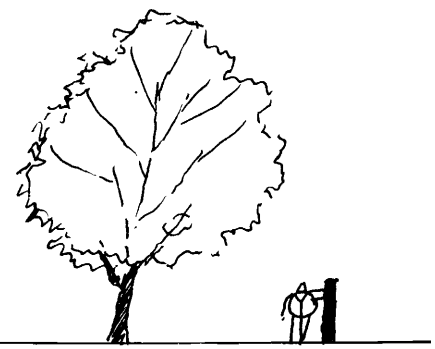


TREE: LARGE DECIDUOUS

QUERCUS BOREALIS (RUBRA) (RED OAK)







Characteristics:

Form: Young - upright
Mature - ovoid, globular

Shade Density: Dense

Growth Rate: Moderate
18-24"/year

Size at 5 Years: 20-30'

Size at Maturity: 75-100' high
75-100' wide

Seasonal Leafout: Late spring

Seasonal Leafdrop: Late fall

Requirements:

Light: Shade to full sun
Very tolerant

Soil Texture: Moderately coarse to fine

Minimum Soil Depth: 30-36"

Water: Moderate to moist
Prefers good drainage

Nutrients: Acid preferred

Container Tolerance: Poor/large 4x6' container for 10 years

Maintenance: Medium

Cost:

Nursery Wholesale: 2" cal. $70-80 BB
4" cal. $200-225 BB

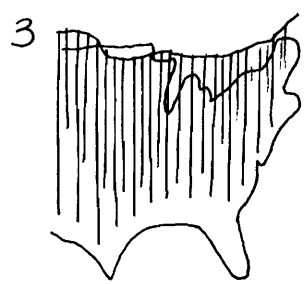
Installation Total: 2.5-3 x wholesale

References:

Hightshoe (1978)
Robinson (1960)

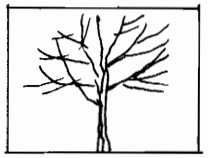
Notes:

- Typical spacing: 30-50' o.c.
- Rapid growth for an oak
- Disease and insect problems
- Sensitive to compacted soils



TREE: LARGE DECIDUOUS

QUERCUS PHELLOS (WILLOW OAK)



Characteristics:

Form: Young - conical
Mature - round topped

Shade Density: Light to medium

Growth Rate: Moderate to rapid
18-36"/year

Size at 5 Years: 20-25'

Size at Maturity: 45-50' high
30-40' spread

Seasonal Leafout: late spring

Seasonal Leafdrop: late fall (semi-evergreen in South)

Requirements:

Light: Full sun to partial shade

Soil Texture: Coarse to fine

Minimum Soil Depth: 30-36" min.

Water: Very moist to moderate
Tolerates poor drainage

Nutrients: Prefers acid

Container Tolerance: Low; large, short-term only

Maintenance: Low

Cost:

Nursery Wholesale: 2-2½" cal. - $115-130
5-6" cal. - $415-475

Installation Total: 2.5-3 x wholesale

References:

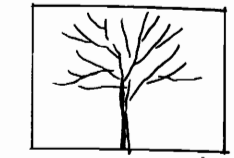
Hudak (1980)
Wyman (1974)
Robinson (1960)

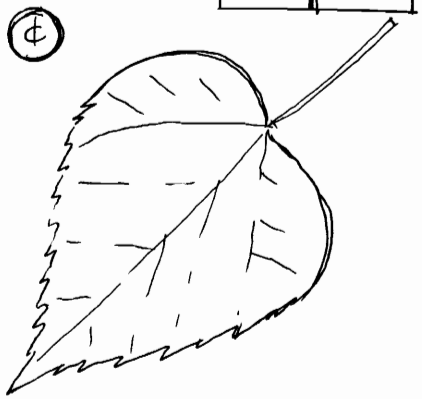
Notes:

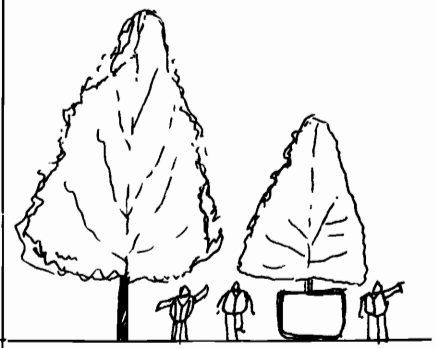
- Typical spacing: 20-25' o.c.
- Widely planted in South
- Good street tree, prefers large planter space
- Tolerates seashore areas

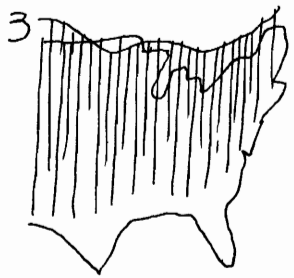
TREE: LARGE DECIDUOUS

TILIA CORDATA (LITTLE LEAF LINDEN)









Characteristics:

Form: Upright, pyramidal

Shade Density: Very dense

Growth Rate: Slow to moderate (fast when young)

Size at 5 Years: 20-30'

Size at Maturity: 60-80' height
30-40' spread

Seasonal Leafout: Mid-spring

Seasonal Leafdrop: Late fall

Requirements:

Light: Sun to partial shade

Soil Texture: Coarse to fine

Minimum Soil Depth: 30-36"

Water: Moist to moderate

Nutrients: Tolerant

Container Tolerance: Good
10-15 years

Maintenance: Low to medium

Cost:

Nursery Wholesale: 10-12' BB - $45-50
2" cal. BB - $85-90
4" cal. BB - $200-225

Installation Total: 2.5-3.0 x wholesale

References:

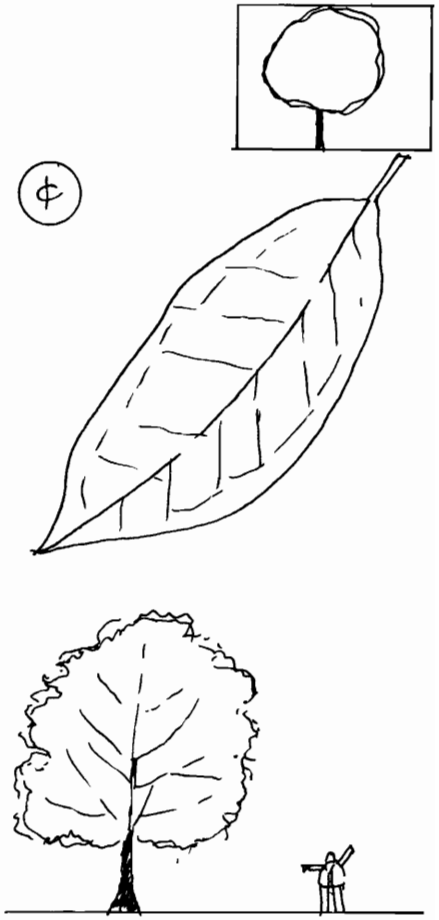
Wyman (1974)
Hudak (1980)
Sunset (1979)
Robinson (1960)

Notes:

- Typical spacing: 20-30' o.c.
- Aphids, honeydew, mold, scale
- Good pollution tolerance
- Cult. "Greenspire" - uniform pyramidal growth, many other cultivars available
- Widely planted in downtowns
- Available in large sizes

TREE: LARGE EVERGREEN

MAGNOLIA GRANDIFLORA (SOUTHERN MAGNOLIA)



Characteristics:

Form:	Rounded to pyramidal
Shade Density:	Very dense
Growth Rate:	Moderate
Size at 5 Years:	25-30'
Size at Maturity:	Large, 75x75'
Seasonal Leafout:	Evergreen
Seasonal Leafdrop:	--

Requirements:

Light:	Full sun to partial shade
Soil Texture:	Coarse to fine Prefers good drainage
Minimum Soil Depth:	30-36"
Water:	Moist to moderate
Nutrients:	Neutral to slightly acid
Container Tolerance:	Short-term only Very large
Maintenance:	Low

Cost:

Nursery Wholesale:	5-6' BB $45-50 11-12' BB $180-200
Installation Total:	2.5-3 x wholesale

References:

Hudak (1980)
Sunset (1979)

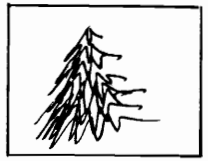
Notes:

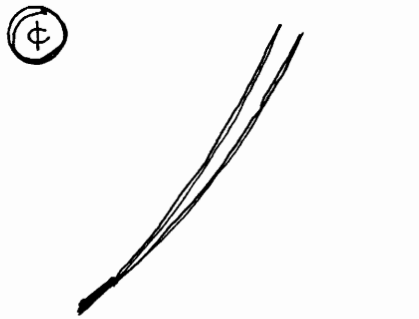
- Typical spacing: 25-50' o.c.
- Dense surface roots

Alt. - Magnolia virginiana

TREE: LARGE EVERGREEN

PINUS NIGRA (AUSTRIAN PINE, AUSTRIAN BLACK PINE)



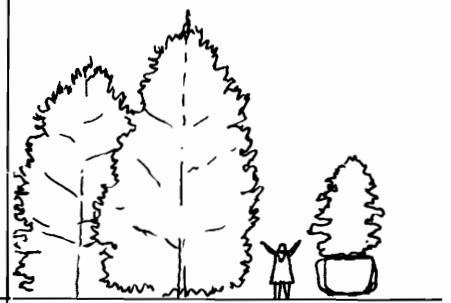


Characteristics:

Form:	Stout pyramidal Flat topped when older
Shade Density:	Dense
Growth Rate:	Moderate to rapid
Size at 5 Years:	15-25'
Size at Maturity:	60-100' 30-50' spread
Seasonal Leafout:	Evergreen
Seasonal Leafdrop:	--

Requirements:

Light:	Full sun to partial shade
Soil Texture:	Coarse to fine
Minimum Soil Depth:	30-36"
Water:	Moderate to drought-tolerant when established
Nutrients:	Neutral to acid, prefers acid
Container Tolerance:	Low, short-term only 6x4' min. cont.
Maintenance:	Low

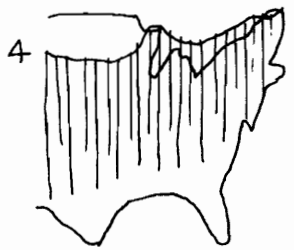


Cost:

Nursery Wholesale:	18-24"BB/cont - $8-10 7-8' BB - $90-100
Installation Total:	2.5 x wholesale

Notes:

- Typical spacing: 15-25' o.c.
- Can be used as hedge, windscreen, or forest mass
- Tolerates high pollution, seacoast and windy locations

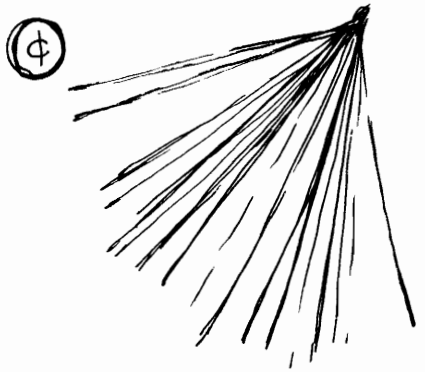


References:

Wyman (1974)
Hudak (1980)
Sunset (1979)
Robinson (1960)

TREE: LARGE EVERGREEN

PINUS STROBUS (WHITE PINE)

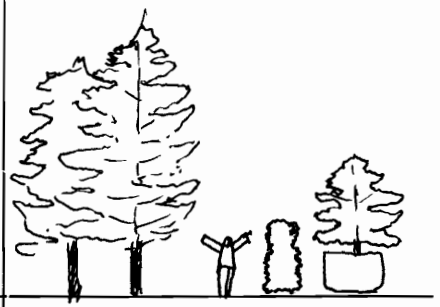


Characteristics:

Form:	Upright, irregular, branching in horizontal tiers
Shade Density:	Very dense No undergrowth
Growth Rate:	Moderate--18-24"/year Rapid when young
Size at 5 Years:	25-35'
Size at Maturity:	Large, 75' high x 50' wide
Seasonal Leafout:	Evergreen
Seasonal Leafdrop:	--

Requirements:

Light:	Full sun to partial shade
Soil Texture:	Coarse to fine Well drained
Minimum Soil Depth:	30-36" for 10 years
Water:	Moderate to moist
Nutrients:	Neutral to acid, prefers acid
Container Tolerance:	Fair Large containers only (4'x6')
Maintenance:	Low



Cost:

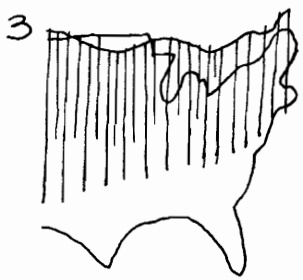
Nursery Wholesale:	7-8'BB - $25-30 16-18'BB - $175-200
Installation Total:	2-2.5 x wholesale

References:

Hightshoe (1978)
Robinson (1960)

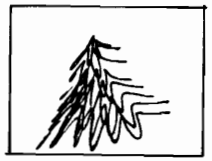
Notes:

- Typical spacing: 20-25' o.c. in groves
- Frequent insect and disease problems
- Sensitive to urban pollution, salt, drought, heat and compacted soils
- Used as dense fast hedge or closed canopy forest
- Little understory growth under forest stands

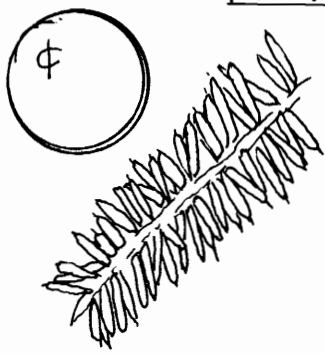


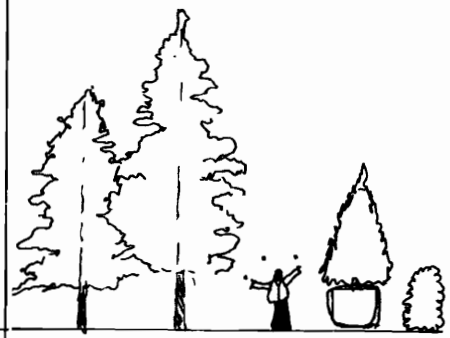
TREE: LARGE EVERGREEN

TSUGA CANADENSIS (HEMLOCK)



Characteristics:		Requirements:	
Form:	Broadly conical	Light:	Full sun to dense shade
Shade Density:	Very dense	Soil Texture:	Medium to coarse
Growth Rate:	Slow to moderate 6-18"/year	Minimum Soil Depth:	24-30" for 20'height
Size at 5 Years:	20-25'	Water:	Moderate to moist, tolerates poor drainage
Size at Maturity:	75'high x 35'wide	Nutrients:	Prefers acid
Seasonal Leafout:	Evergreen	Container Tolerance:	Good, if kept in clipped balance with container soils available
Seasonal Leafdrop:	--	Maintenance:	Low



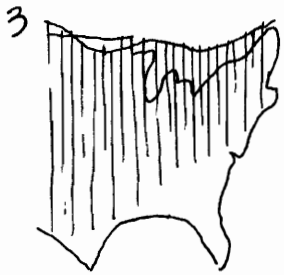


Cost:	
Nursery Wholesale:	Hedge 18-24" BB - $6 7-8' BB - $50-60
Installation Total:	2 x wholesale

References:
Hightshoe (1978) Robinson (1960)

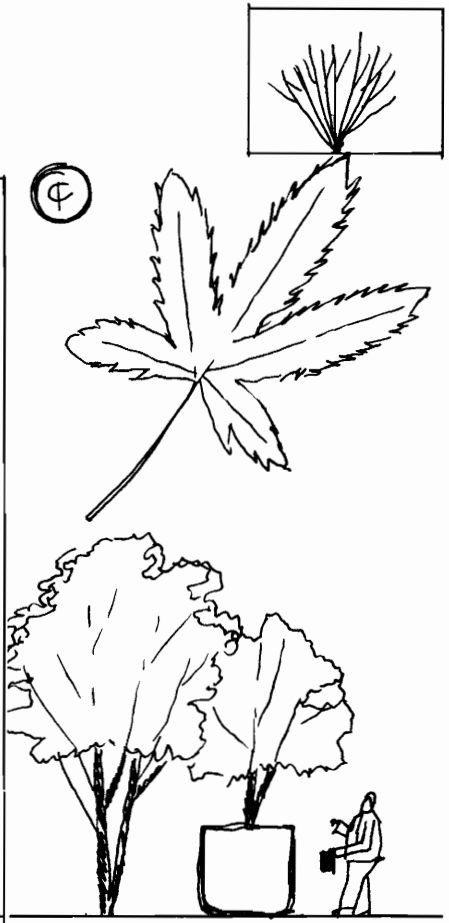
Notes:

- Typical spacing: hedge 6' o.c.
  stand 10-15' o.c.
- Shears well to form hedge
- Few disease problems
- Sensitive to lighting, salts, drought, heat and compacted soils



TREE: SMALL DECIDUOUS

ACER PALMATUM (JAPANESE MAPLE)



Characteristics:

Form:	Broad canopy
Shade Density:	Light to medium
Growth Rate:	Slow to moderate
Size at 5 Years:	10-15'
Size at Maturity:	20-25'
Seasonal Leafout:	Early to mid-spring
Seasonal Leafdrop:	Mid-fall

Requirements:

Light:	Full sun to deep shade
Soil Texture:	Coarse to medium
Minimum Soil Depth:	18-24"
Water:	Moist to moderate
Nutrients:	Prefers acid
Container Tolerance:	Very good, long-term 4x3' container
Maintenance:	Low

Cost:

Nursery Wholesale:	5 gal. cont. $15-20 15' BB spread $250-300
Installation Total:	2.5 x wholesale

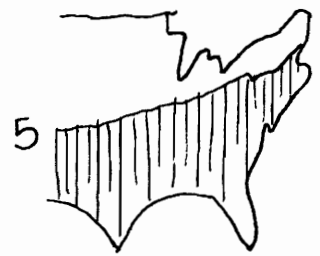
Notes:

- Good for smaller street tree
- Often kept clipped at smaller sizes for long-term
- Foliage very light and airy

References:

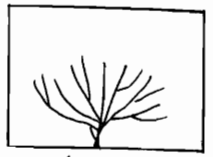
Hudak (1980)
Sunset (1979)
Wyman (1974)

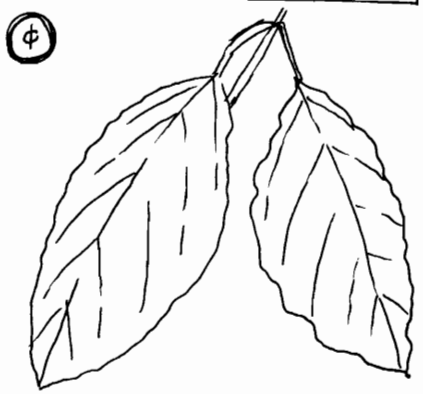
Cultivars
- many smaller red-leafed forms
- leaves vary, finely cut to typical size

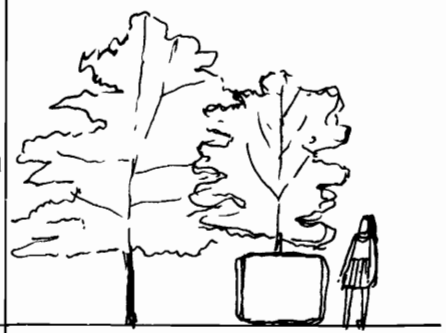


TREE: SMALL DECIDUOUS

CORNUS FLORIDA (DOGWOOD)







Characteristics:		Requirements:	
Form:	Globular	Light:	Full sun to dense shade
Shade Density:	Medium	Soil Texture:	Coarse to fine
Growth Rate:	Slow to moderate 12-18"/year	Minimum Soil Depth:	15-18"
Size at 5 Years:	12-18'	Water:	Moist to moderate Will tolerate some dryness
Size at Maturity:	35x25'	Nutrients:	Slightly acid pH preferred
Seasonal Leafout:	Mid-spring	Container Tolerance:	Very good; long-term in 3'x4' containers
Seasonal Leafdrop:	Mid-fall	Maintenance:	Low

Cost:

Nursery Wholesale: 3-4' $11-12 BB
10-12' $90-100 BB

Installation Total: 2 x wholesale

References:

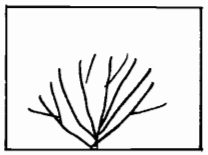
Hightshoe (1978)
Robinson (1960)

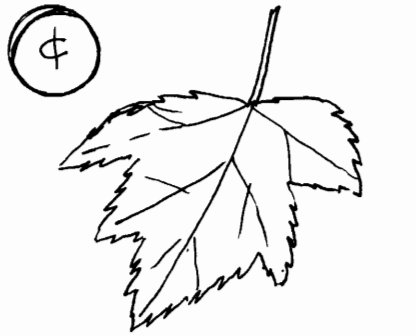
Notes:

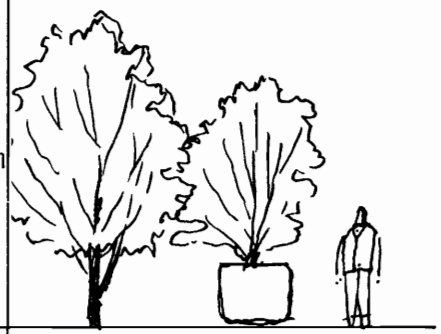
- Typical spacing: 8-10 o.c., cluster
- Few insect and disease problems
- Sensitive to drought, lighting, and compacted soils
- Cultivars for form and flower color

TREE: SMALL DECIDUOUS

CRATAEGUS PHAENOPYRUM (CORDATA) (WASHINGTON HAWTHORN)







Characteristics:

Form:	Ovoid/globular Multi-stem
Shade Density:	Medium
Growth Rate:	Fast when young, then slow after - 6-12"/yr
Size at 5 Years:	15-20'
Size at Maturity:	Small - 25' x 20'
Seasonal Leafout:	Late spring
Seasonal Leafdrop:	Late fall

Requirements:

Light:	Full sun Does not tolerate shade
Soil Texture:	Coarse to fine
Minimum Soil Depth:	18-24"
Water:	Prefers moist, will tolerate drought
Nutrients:	Acid to alkaline
Container Tolerance:	Very good, long-term in 3'x4' containers
Maintenance:	Medium to high

Cost:

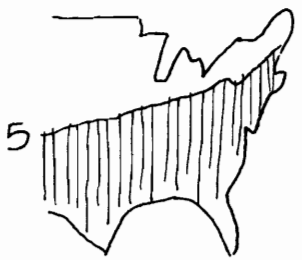
	4-12' BB available
Nursery Wholesale:	5-6' BB $18-20 10-12' BB $70-75
Installation Total:	2 x wholesale

References:

Hightshoe (1978)
Robinson (1960)

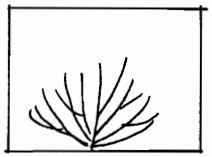
Notes:

- Typical spacing: 15-20' o.c. or clumps
- Commonly used
- Very thorny branches, widely planted as barrier
- Red berries through winter
- Frequent disease, fireblight, rust and insect problems
- Sensitive to salt

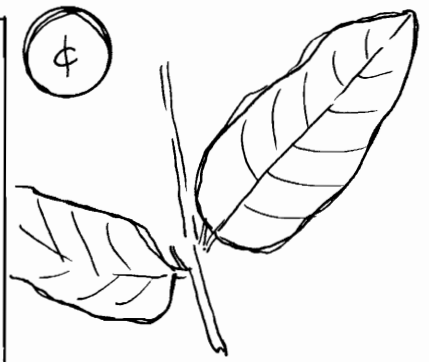


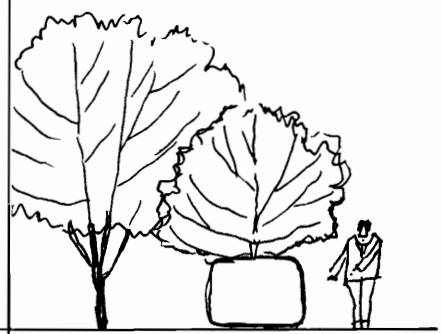
TREE: SMALL DECIDOUS

LAGERSTROMEIA INDICA (CRAPE MYRTLE)



Characteristics:		Requirements:	
Form:	Multi-stem, spreading	Light:	Full sun to partial shade
Shade Density:	Light to medium	Soil Texture:	Coarse to fine
Growth Rate:	Rapid - 18-24"/year	Minimum Soil Depth:	24-30"
Size at 5 Years:	12-18'	Water:	Drought resistant
Size at Maturity:	Varies, 10-25'	Nutrients:	Slightly acid to neutral
Seasonal Leafout:	Spring	Container Tolerance:	Good, long-term in 3'x4' container
Seasonal Leafdrop:	Fall	Maintenance:	Medium





Cost:	
Nursery Wholesale:	18-24 " cont. $6-10 4-5' BB $17-20 8-10' BB $70-80 12-14' BB $120-130
Installation Total:	2.5 x wholesale

Notes:

- Typical spacing: 10-15 ft. o.c.
- Hardy north to Baltimore, very common in south
- Long period of summer blooming

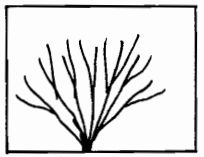
Cultivars - for flower colors and size

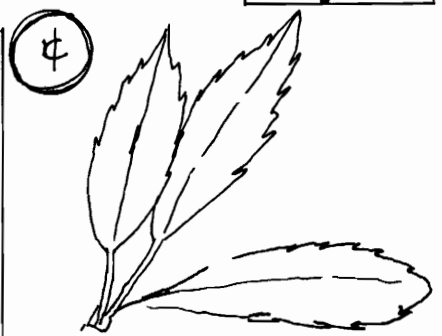
References:

Sunset (1979)

TREE: SMALL DECIDUOUS

MALUS FLORIBUNDA (JAPANESE FLOWERING CRABAPPLE)



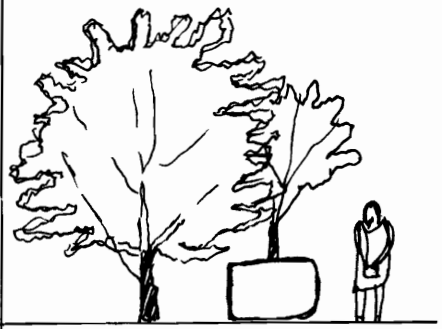


Characteristics:

Form:	Broad, round-topped, shrubby tree
Shade Density:	Medium to light
Growth Rate:	Moderate to rapid
Size at 5 Years:	10-15'
Size at Maturity:	20-30' x 20-30'
Seasonal Leafout:	Mid-spring
Seasonal Leafdrop:	Mid-fall

Requirements:

Light:	Full sun to partial shade
Soil Texture:	Coarse to fine
Minimum Soil Depth:	24-30" min.
Water:	Moist to moderate
Nutrients:	Tolerant, prefers neutral
Container Tolerance:	Very good, long-term in 4x3' container
Maintenance:	Low to medium, varies with location



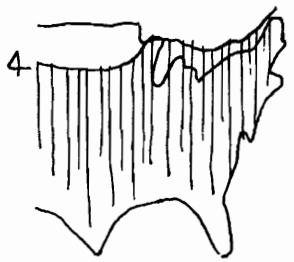
Cost:

Nursery Wholesale:	BB 8-10' $14-17 BB 8-10' $40-50 BB 3-4"cal. $100-150
Installation Total:	2.5 x wholesale

Notes:

- Typical spacing: 12-15' o.c.
- Spring bloom outstanding
- Small yellow winter apples

Alt. - two hundred crabapples to choose among

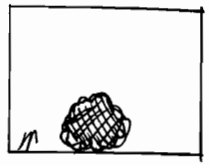


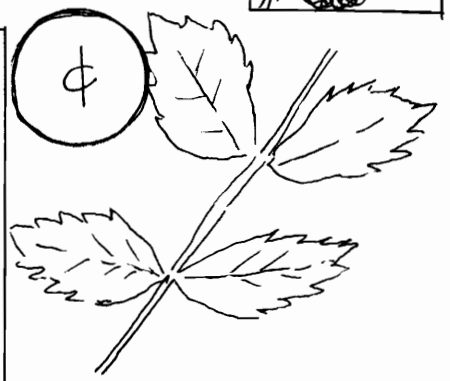
References:

Wyman (1974)
Sunset (1979)
Robinson (1960)
Hudak (1980)

SHRUB: DECIDUOUS AND SEMI-EVERGREEN

ABELIA GRANDIFLORA (GLOSSY ABELIA)





Characteristics:

Form:	Rounded with arching base
Shade Density:	Dense
Growth Rate:	Rapid
Size at 5 Years:	8-10'
Size at Maturity:	8-10'
Seasonal Leafout:	Loses leaves below 10-15° F
Seasonal Leafdrop:	Semi-evergreen elsewhere

Requirements:

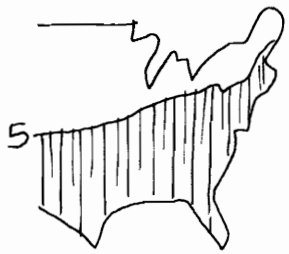
Light:	Full sun to partial shade
Soil Texture:	Coarse to fine
Minimum Soil Depth:	12-15" min. 18-24" ideal
Water:	Drought-tolerant to moist
Nutrients:	Tolerant
Container Tolerance:	Good, tolerates small containers
Maintenance:	Low

Cost:

Nursery Wholesale:	2-3' BB $4.50 2-gal. cont. $5-6
Installation Total:	2 x wholesale

Notes:

- Typical spacing: 4-5' o.c.
- Clip to maintain dense form, fast new growth
- Blooms all summer

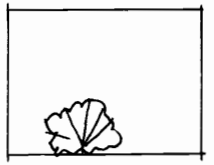


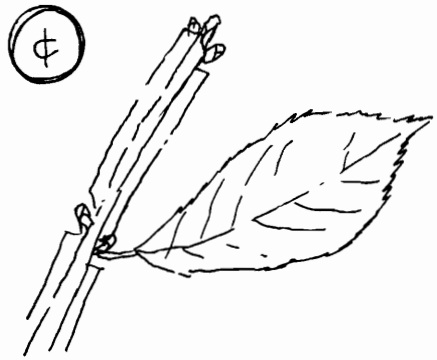
References:

Wyman (1977)
Sunset (1979)

SHRUB: DECIDUOUS AND SEMI-EVERGREEN

EUONYMOUS ALATUS (WINGED EUONYMOUS, BURNING BUSH)



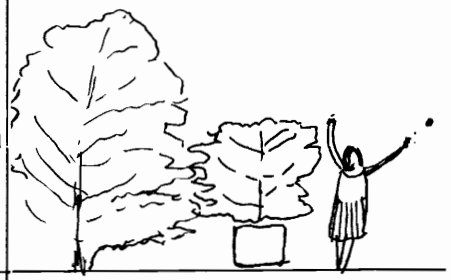


Characteristics:

Form:	Flat topped, rectangular
Shade Density:	Medium to dense
Growth Rate:	Slow to medium
Size at 5 Years:	4-6'
Size at Maturity:	8-12'
Seasonal Leafout:	Mid-spring
Seasonal Leafdrop:	Late fall

Requirements:

Light:	Sun to partial shade
Soil Texture:	Coarse to fine
Minimum Soil Depth:	12-18"
Water:	Moist to drought-tolerant
Nutrients:	Neutral to acid
Container Tolerance:	Good, "Compacta" better for long-term
Maintenance:	Low, thrives with neglect



Cost:

Nursery Wholesale:	12-15"BB/cont	$6.50-7
	24-30"BB	$11-12
Installation Total:	2 x wholesale	

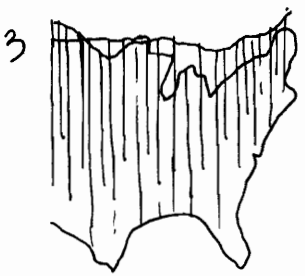
References:

Wyman (1977)
Sunset (1979)
Robinson (1960)

Notes:

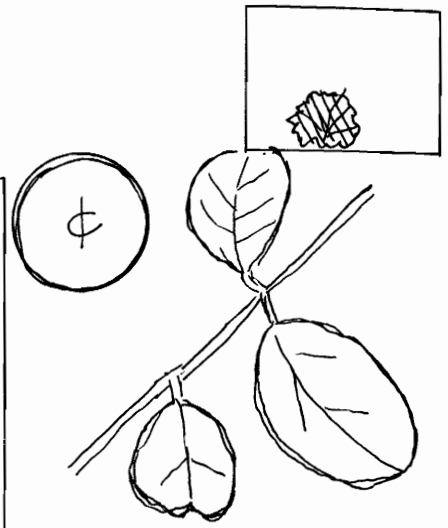
- Typical spacing: 4-6' o.c.
- Winter branches winged and block more sunlight
- Bright red fall color

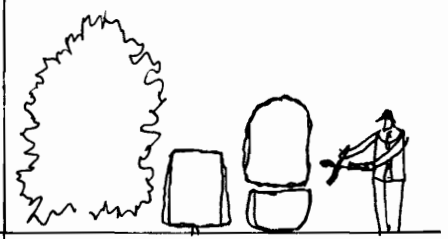
Alt. - Euonymus alatus "Compacta" 4-6' tall



SHRUB: DECIDUOUS AND SEMI-EVERGREEN

LIGUSTRUM OVALIFOLIUM (CALIFORNIA PRIVET)





Characteristics:

Form:	Upright to rounded
Shade Density:	Medium
Growth Rate:	Very rapid
Size at 5 Years:	12-15'
Size at Maturity:	12-15'
Seasonal Leafout:	Early spring
Seasonal Leafdrop:	Late fall; mild winters, evergreen

Requirements:

Light:	Full sun to partial shade
Soil Texture:	Coarse to fine
Minimum Soil Depth:	12-15"
Water:	Drought tolerant to moist
Nutrients:	Low demands
Container Tolerance:	Very good
Maintenance:	Low

Cost:

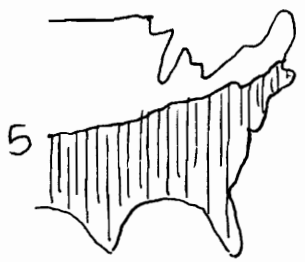
Nursery Wholesale:	12-18" BR $.65-1.00 4-5' BR $2.50-3.50
Installation Total:	2 x wholesale

References:

Wyman (1977)
Sunset (1979)
Robinson (1960)

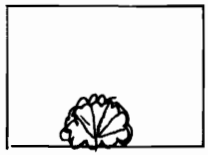
Notes:

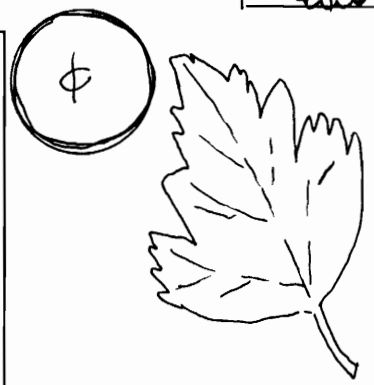
- Typical spacing: 12-15" o.c. for hedges
- Widely planted, among most popular privet hedges
- Inexpensive hedge
- Tolerates heavy pruning



SHRUB: DECIDUOUS AND SEMI-EVERGREEN

SPIRAEA VAN HOUTTEI (VAN HOUTEI SPIREA)



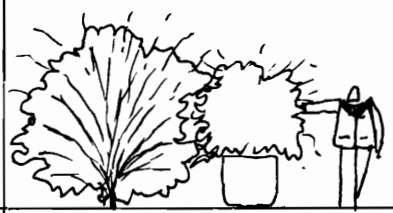


Characteristics:

Form:	Arching vase shape to broad mound
Shade Density:	Light to medium
Growth Rate:	Rapid, 12-24"/year
Size at 5 Years:	6-8'
Size at Maturity:	6-8' height 6' spread
Seasonal Leafout:	Mid-spring
Seasonal Leafdrop:	Mid-fall

Requirements:

Light:	Full sun to partial shade
Soil Texture:	Coarse to fine
Minimum Soil Depth:	12-15"
Water:	Moist to drought-tolerant
Nutrients:	Tolerant
Container Tolerance:	Good, long-term
Maintenance:	Low



Cost:

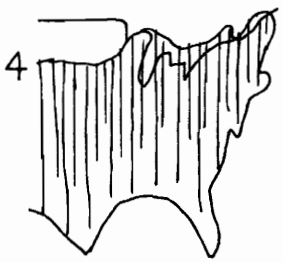
Nursery Wholesale:	18-24" BR $2.40-2.90 2-3' BB $6-7
Installation Total:	2 x wholesale

References:

Wyman (1977)
Sunset (1979)
Robinson (1960)

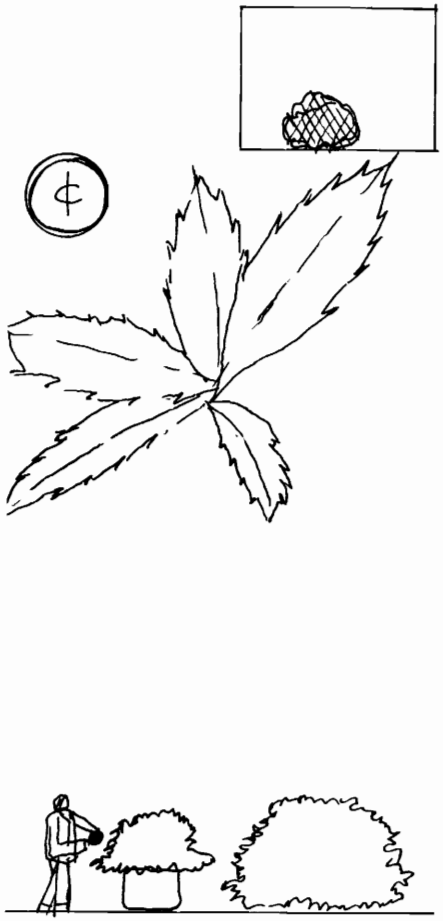
Notes:

- Typical spacing: 3-4' o.c. for hedge
- Large rounded hedge



SHRUB: EVERGREEN

BERBERIS JULIANAE (WINTERGREEN BARBERRY)



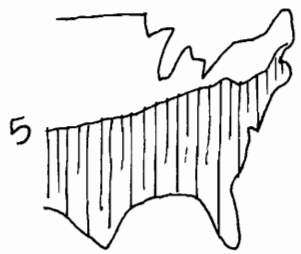
Characteristics:		Requirements:	
Form:	Dense upright	Light:	Full sun to partial shade
Shade Density:	Very dense	Soil Texture:	Coarse to fine
Growth Rate:	Moderate	Minimum Soil Depth:	12-15"
Size at 5 Years:	4-5'	Water:	Moist to drought-tolerant
Size at Maturity:	5-6'	Nutrients:	No special needs
Seasonal Leafout:	Evergreen	Container Tolerance:	Good
Seasonal Leafdrop:	--	Maintenance:	Low

Cost:	
Nursery Wholesale:	12-15" BB or cont. $6.50-7.50 24-20" BB $14-16
Installation Total:	2 x wholesale

References:	
	Wyman (1977) Sunset (1979)

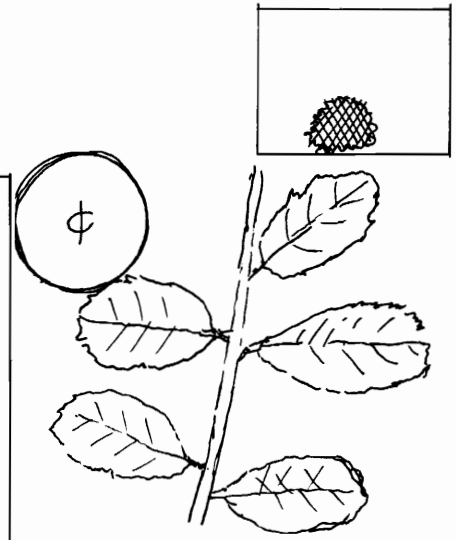
Notes:

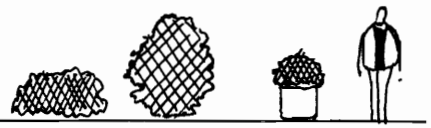
- Typical spacing: 4-5' o.c.
- Very dense and thorny, formidable barrier hedge
- Very tolerant of abuse and difficult conditions



SHRUB: EVERGREEN

ILEX CRENATA (JAPANESE HOLLY)





Characteristics:

Form:	Upright to rounded
Shade Density:	Medium to dense
Growth Rate:	Slow to moderate
Size at 5 Years:	3-4'
Size at Maturity:	4-5' Some varieties to 20'
Seasonal Leafout:	Evergreen
Seasonal Leafdrop:	--

Requirements:

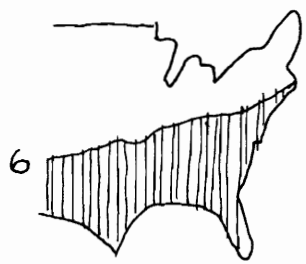
Light:	Full sun to partial shade
Soil Texture:	Coarse to medium
Minimum Soil Depth:	12-15"
Water:	Moist to moderate
Nutrients:	Slightly acid
Container Tolerance:	Very good Long-term
Maintenance:	Low

Cost:

Nursery Wholesale:	12-15" cont.	$5.50-6.50
	18-24" cont/BB	$8-12
	30-36"	$16-18
Installation Total:	2 x wholesale	

Notes:

- Typical spacing: 24-30" o.c. (hedge)
- Ideal for hedges, similar to boxwood

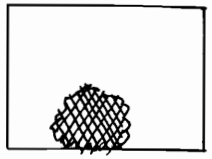


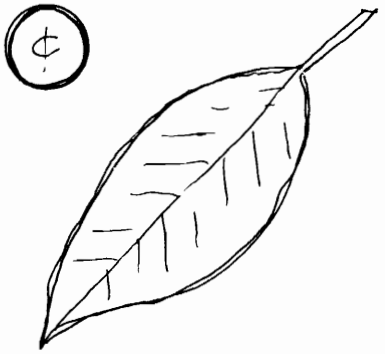
References:

Wyman (1977)
Sunset (1979)
Robinson (1960)

SHRUB: EVERGREEN

LIGUSTRUM LUCIDUM (WAX LEAF PRIVIT, GLOSSY PRIVIT)



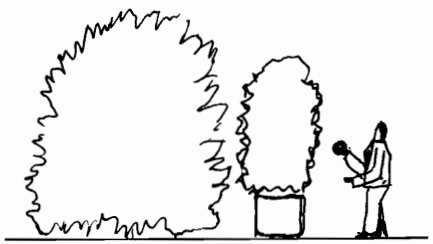


Characteristics:

Form:	Spreading to upright
Shade Density:	Very dense
Growth Rate:	Very rapid
Size at 5 Years:	10-15'
Size at Maturity:	20-30'
Seasonal Leafout:	Evergreen
Seasonal Leafdrop:	--

Requirements:

Light:	Full sun to shade
Soil Texture:	Coarse to fine
Minimum Soil Depth:	15-24"
Water:	Moist to drought-tolerant when established
Nutrients:	Tolerant
Container Tolerance:	Good
Maintenance:	Low



Cost:

Nursery Wholesale:	15-18"BB/cont.	$6-7.50
	30-36"BB	$10-12
Installation Total:	2 x wholesale	

Notes:

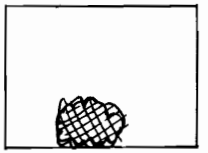
- Typical spacing: 3-4' o.c. for hedge 8-10' o.c./screen
- Glossy foliage, clips well, widely planted

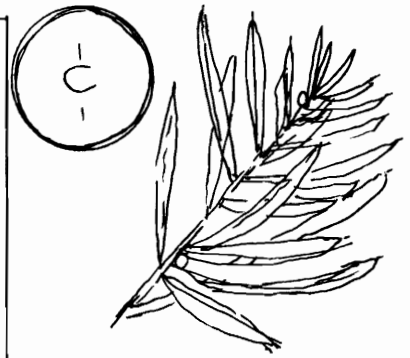
References:

Wyman (1977)
Sunset (1979)

SHRUB: EVERGREEN

TAXUS CUSPIDATA (JAPANESE YEW)



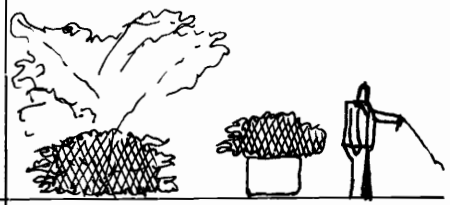


Characteristics:

Form:	Spreading to upright cultivars
Shade Density:	Very dense
Growth Rate:	Slow 6-12"/year
Size at 5 Years:	5-10'
Size at Maturity:	Very large; cultivars vary 10-50' in height
Seasonal Leafout:	Evergreen
Seasonal Leafdrop:	--

Requirements:

Light:	Full sun to partial shade Burns with reflected heat
Soil Texture:	Coarse to fine
Minimum Soil Depth:	12-24"
Water:	Moderate to moist
Nutrients:	Prefers neutral soils
Container Tolerance:	Good for small cultivars
Maintenance:	Low



Cost:

Nursery Wholesale:	12-15"BB - $10-12 18-24"BB - $12-20
Installation Total:	2 x wholesale

References:

Wyman (1977)
Sunset (1979)
Robinson (1960)

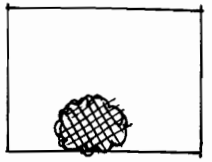
Notes:

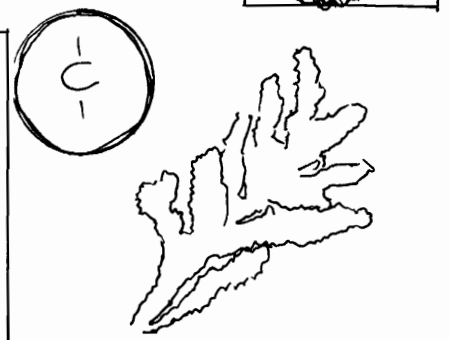
- Typical spacing: 3-4' o.c. (hedge); 10-12 o.c. (specimens)
- Clips well for hedges, buffers, screens
- More shade and moisture tolerant than other conifers.

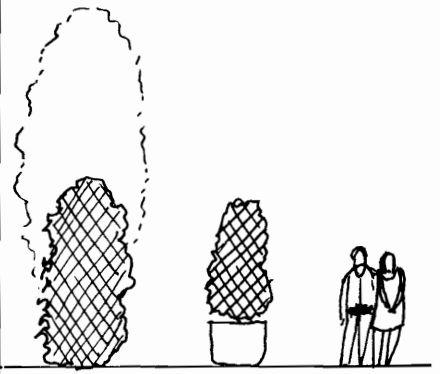
Cultivars - large number of forms available

SHRUB: EVERGREEN

THUJA OCCIDENTALIS (ARBORVITAE)







Characteristics:		Requirements:	
Form:	Upright, symmetrical	Light:	Full sun to partial shade
Shade Density:	Dense	Soil Texture:	Coarse to medium
Growth Rate:	Moderate to slow	Minimum Soil Depth:	18-24"
Size at 5 Years:	6-8'	Water:	Moderate to moist
Size at Maturity:	Upright: 25-40' Spreading: 4-5'	Nutrients:	Prefers rich soil
Seasonal Leafout:	Evergreen	Container Tolerance:	Good if moist
Seasonal Leafdrop:	--	Maintenance:	Low

Cost:

Nursery Wholesale: 18-24"BB - $7.50-9.00
4-5'BB - $22-25

Installation Total: 2 x wholesale

References:

Wyman (1977)
Sunset (1979)
Robinson (1960)

Notes:

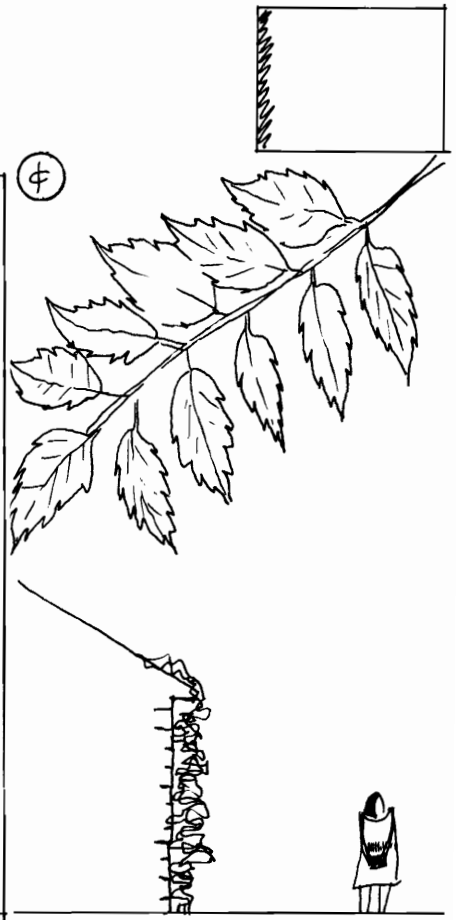
- Typical spacing: spreading 3-4' o.c.; upright 6' o.c.
- Can be sheared to form solid hedge

Cultivars - many for different shapes:
"Fastigiata" - columar, tall
"Globosa" - rounded, small

VINE

CAMPSIS RADICANS (BIGNONIA RADICANS) (TRUMPET VINE)

Characteristics:		Requirements:	
Form:	Climbing	Light:	Full sun to partial shade
Shade Density:	Dense	Soil Texture:	Coarse to medium, well drained
Growth Rate:	Moderate to rapid 10'/year	Minimum Soil Depth:	12-15"
Size at 5 Years:	25-25'	Water:	Moderate
Size at Maturity:	30-40'+	Nutrients:	
Seasonal Leafout:	late spring	Container Tolerance:	Good 3-4 years in 12-15" containers
Seasonal Leafdrop:	mid to late fall	Maintenance:	Low



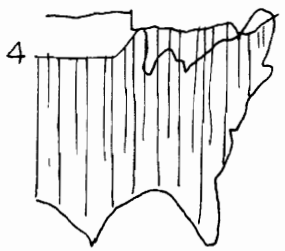
Cost:	
Nursery Wholesale:	2 yr. 6" cans - $4-5
Installation Total:	2 x wholesale

References:	Wyman (1977) Sunset (1979) Perkins (1964) Robinson (1960)

Notes:

- Typical spacing: 10-15' o.c. on walls
- Top-heavy when older, requires thinning to lighten top
- Few insect pests
- Rootlike holdfasts and twining stems
- Often require extra support because of added weight

Alt. - Campsis grandiflora (Zone 7)
(Chinese Trumpet Vine)



VINE

CELASTRUS SCANDENS (AMERICAN BITTERSWEET)

Characteristics:		Requirements:	
Form:	Twining vine	Light:	Full sun to shade
Shade Density:	Medium	Soil Texture:	Coarse to fine
Growth Rate:	Moderate to rapid 10'/year	Minimum Soil Depth:	12-18"
Size at 5 Years:	15-20'	Water:	Tolerant, moist to dry
Size at Maturity:	25-35' Needs a lot of room	Nutrients:	Tolerant--prefers neutral
Seasonal Leafout:	Mid-spring	Container Tolerance:	Good
Seasonal Leafdrop:	Mid-fall	Maintenance:	Low

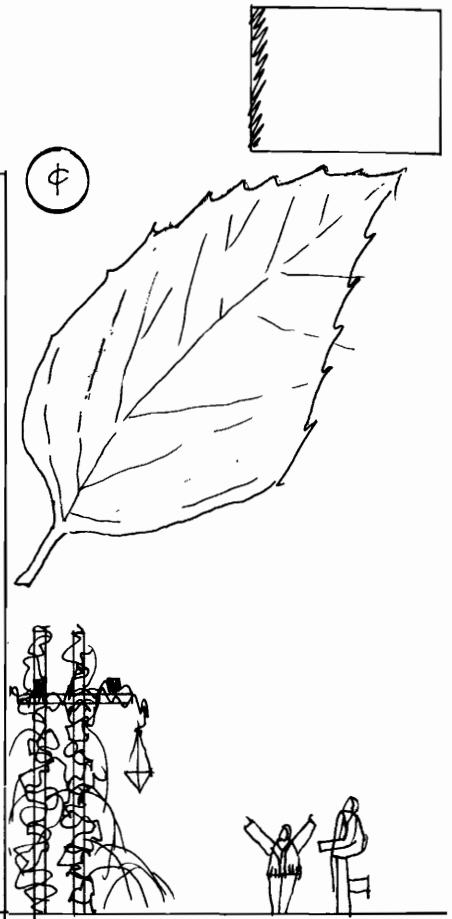
Cost:	
Nursery Wholesale:	18-24" 1 yr. $2-2.50 2-3' 2 yr. $2.50-3.50
Installation Total:	2 x wholesale

References:
Wyman (1977)
Perkins (1964) (4)
Sunset (1979)
Robinson (1960)

Notes:

- Typical spacing: 5-10' o.c.
- Easy to grow, few pests, dense and sprawling, intertwining
- Support: trellis, fences, or low walls, etc.
- Vigorous--can choke out adjacent shrubs
- Orange fruits in fall

Alt. - Celastrus orbiculatus (Oriental Bittersweet)



VINE

CLEMANTIS PANICULATA (DIOSCOREIFOLIA) (SWEET AUTUMN CLEMANTIS)

Characteristics:		Requirements:	
Form:	Twining stems	Light:	Full sun to partial shade
Shade Density:	Dense	Soil Texture:	Coarse/mulch surface
Growth Rate:	Moderate to rapid up to 15'/year	Minimum Soil Depth:	12-18"
Size at 5 Years:	15-20'	Water:	Prefers moderate to moist
Size at Maturity:	30'	Nutrients:	Neutral to acid
Seasonal Leafout:	mid-spring	Container Tolerance:	Good, long-term
Seasonal Leafdrop:	mid to late fall	Maintenance:	Low

Cost:	
Nursery Wholesale:	2 yr. 3" pots $2.50-3 2-3' cont. $6-7 3-4' cont. $7-8
Installation Total:	2 x wholesale

References:
Perkins (1964) (4) Wyman (1977) Sunset (1979) Robinson (1960)

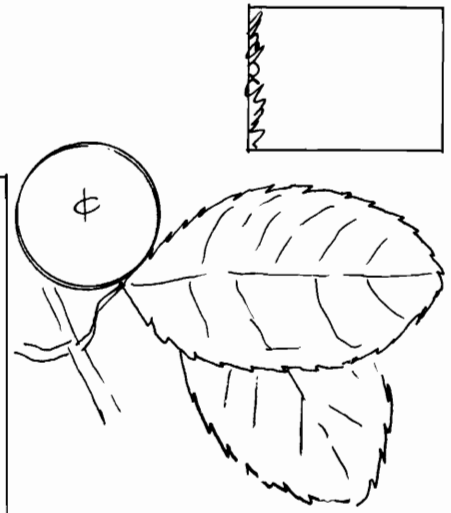
Notes:

- Typical spacing: 5-10'
- Few disease or insect problems
- Among easiest clemantis to grow
- Prune yearly
- Support: tendril-like leaf stems, trellis support.
- Brittle/tender when young
- Tolerant of seaside environment

Alt. - Clemantis armandii (Evergreen)
Clemantis montana

VINE

EUONYMOUS FORTUNEI COLORATUS (PURPLE LEAF WINTERCREEPER)



Characteristics:

Form:	Groundcover or clinging vine
Shade Density:	Dense
Growth Rate:	Rapid
Size at 5 Years:	Infills solid within one year; 10-15' on walls; mounds 18"
Size at Maturity:	
Seasonal Leafout:	Evergreen
Seasonal Leafdrop:	--

Requirements:

Light:	Full sun to dense shade
Soil Texture:	Coarse to fine
Minimum Soil Depth:	4-6"
Water:	Drought-tolerant to moist
Nutrients:	Low requirements
Container Tolerance:	Very good
Maintenance:	Low

Cost:

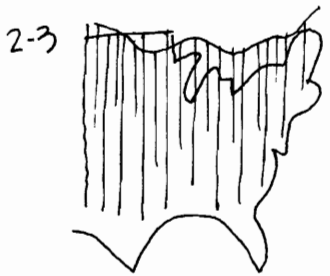
Nursery Wholesale:	2¼-2½" pots - $.40- 9-12" runners - $.50 1-gal. cont. - $3.00
Installation Total:	2 x wholesale

References:

Wyman (1977)
Sunset (1979)

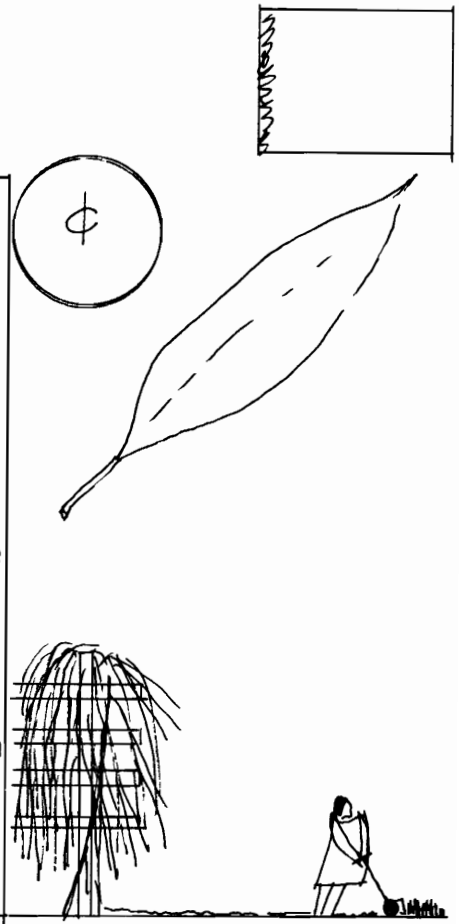
Notes:

- Typical spacing: 12-18" o.c. from 2" pots; 3' o.c. at base of wall
- Support: climbs by rootlet holdfasts, trails over walls and banks
- Few insect pests
- Good for erosion control
- Dense cover chokes out weeds
- Should be clipped back at edges



VINE

GELSEMIUM SEMPERVIRENS (CAROLINA YELLOW JESSAMINE)



Characteristics:

Form:	Twining vine
Shade Density:	Light, delicate
Growth Rate:	Moderate
Size at 5 Years:	15-20'
Size at Maturity:	20-25'
Seasonal Leafout:	Evergreen
Seasonal Leafdrop:	--

Requirements:

Light:	Full sun to shade
Soil Texture:	Coarse to medium
Minimum Soil Depth:	12-15"
Water:	Drought-tolerant to moderate
Nutrients:	Acid preferred
Container Tolerance:	Very good, long-term
Maintenance:	Low

Cost:

Nursery Wholesale:	1 gal. cont. - $4 2-3' cont. - $6-7 3-4' cont. - $7-8
Installation Total:	2 x wholesale

References:

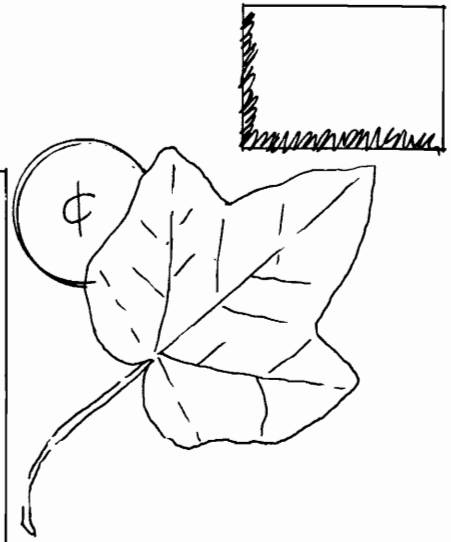
Sunset (1979)
Perkins (1964)

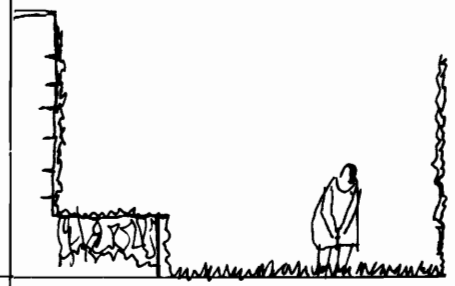
Notes:

- Typical spacing: 4-5' o.c.
- Few pests
- Support: twining stems, good trellis or bank cover
- Spring yellow fragrant flowers
- All parts poisonous
- Light movement in wind

VINE

HEDERA HELIX (ENGLISH IVY)





Characteristics:		Requirements:	
Form:	Climbing or spreading clinging woody vine	Light:	Full sun to dense shade
Shade Density:	Very dense	Soil Texture:	Coarse to fine
Growth Rate:	Moderate 4-8'/year	Minimum Soil Depth:	6-10"
Size at 5 Years:	Infill within one year 10-15' on walls	Water:	Drought-tolerant to moist
Size at Maturity:	60-90'	Nutrients:	Neutral to acid
Seasonal Leafout:	Evergreen	Container Tolerance:	Very good
Seasonal Leafdrop:	--	Maintenance:	Low

Cost:

Nursery Wholesale: 2¼" pots - 35-50¢
1 gal. cont. - $3.00

Installation Total: 2 x wholesale

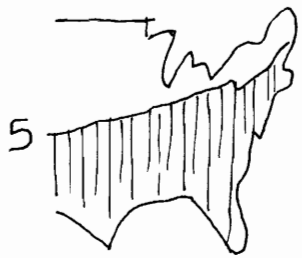
References:

Wyman (1977)
Perkins (1964) Zone 6
Sunset (1979)
Robinson (1960)

Notes:

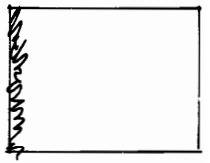
- Typical spacing: vine 18" o.c.
  groundcover 12" o.c.
- Support: aerial rootlets on stems, stem roots in groundcovers
- Yearly shearing to control growth
- Will smother adjacent plants
- Widely used as climber, groundcover or hanging

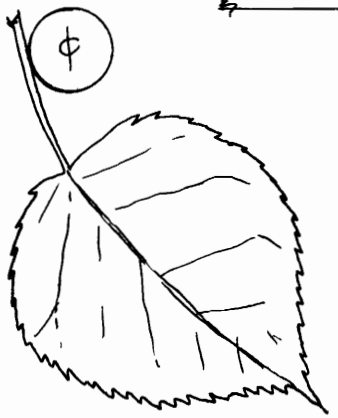
Cultivars - "Baltica" - smaller leaf and hardier to cold

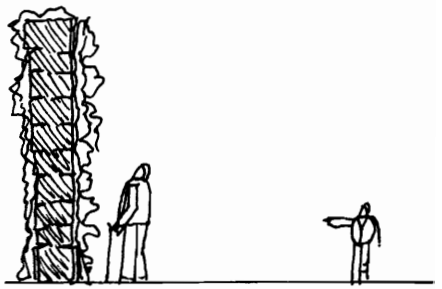


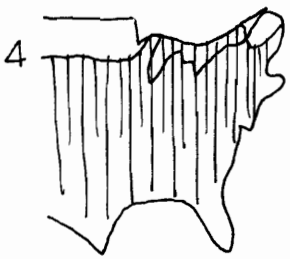
VINE

HYDRANGEA ANOMALA PETIOLARIS (CLIMBING HYDRANGEA)









Characteristics:

Form:	Spreading, climbing
Shade Density:	Dense
Growth Rate:	Slow to moderate, 12-18"/year; slow initial, faster when established
Size at 5 Years:	15-20' on wall
Size at Maturity:	4-5 story building (up to 50-60')
Seasonal Leafout:	Late spring
Seasonal Leafdrop:	Late fall

Requirements:

Light:	Partial shade to full shade
Soil Texture:	Coarse to medium, good drainage
Minimum Soil Depth:	12-18"
Water:	Moderate to moist
Nutrients:	Prefers acid
Container Tolerance:	Very good, long-term
Maintenance:	Low

Cost:

Nursery Wholesale: 15-18"/6" cont.-$5-7
2-3'/8" cont.-$8-10
Installation Total: 2 x wholesale

References:

Wyman (1977)
Sunset (1979)
Perkins (1964) zone 5
Robinson (1960)

Notes:

- Typical spacing: 5' o.c. at base of wall
- Clings to masonry walls
- Small rootlike holdfasts, some supplemental support when young
- Among best of clinging vines

VINE

LONICERA JAPONICA HALLIANA (HALLS HONEYSUCKLE)

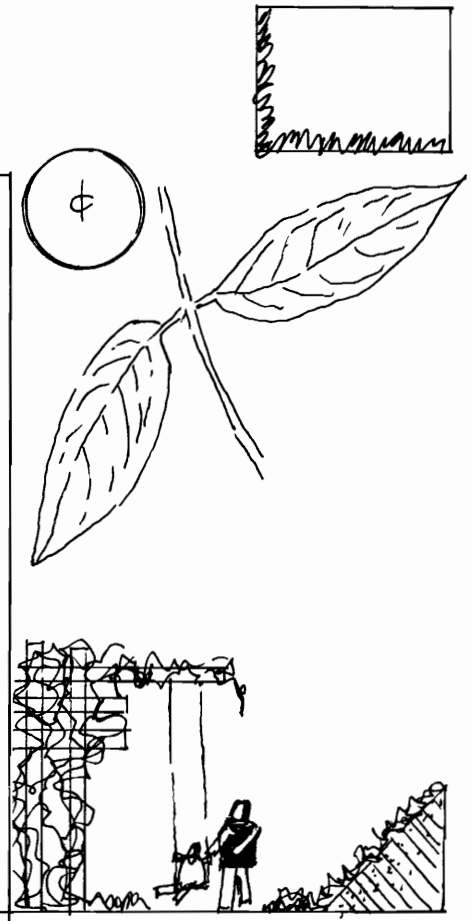
Characteristics:		Requirements:	
Form:	Twining vine	Light:	Sun or shade
Shade Density:	Dense	Soil Texture:	Coarse to fine
Growth Rate:	Very rapid, 18-20'/yr Slow to start	Minimum Soil Depth:	6-12"
Size at 5 Years:	20-25'	Water:	Drought-tolerant to moist
Size at Maturity:	35'	Nutrients:	Wide range
Seasonal Leafout:	Early spring	Container Tolerance:	Very good
Seasonal Leafdrop:	Late fall; evergreen in warm climate	Maintenance:	Low

Cost:	
Nursery Wholesale:	1 yr 2¼" pots - 40-60¢
Installation Total:	2 x wholesale

References:
Sunset (1979)
Wyman (1977)
Perkins (1964)
Robinson (1960)

Notes:

- Typical spacing: wall, 3-4' o.c.; groundcover, 2-3' o.c.
- Support: twining stems, trellis support
- Used for bank/erosion control
- Stems touching ground take root
- Vigorous, can smother adjacent plants
- Few pests
- Buildup of dead leaves
- Cut back yearly to prevent buildup

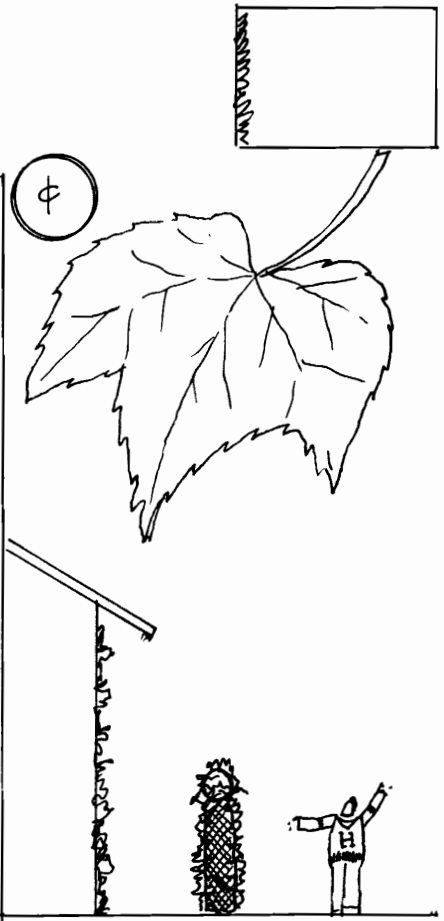


VINE

PARTHENOCISSUS TRICUSPIDATA (BOSTON IVY)

Characteristics:	
Form:	Clinging vine
Shade Density:	Medium to dense
Growth Rate:	Rapid 5-10 SF/year once established
Size at 5 Years:	Cover 1-2 story building
Size at Maturity:	Cover 4-5 stories
Seasonal Leafout:	Late spring
Seasonal Leafdrop:	Late fall

Requirements:	
Light:	Full sun to deep shade
Soil Texture:	Coarse to fine
Minimum Soil Depth:	Tolerates 6-8" Prefers 12-18"
Water:	Moist (drought-tolerant once established)
Nutrients:	Not demanding
Container Tolerance:	Good, long-term
Maintenance:	Low



Cost:	
Nursery Wholesale:	1 yr 2¼" - $.80-1.25 2 yr 2¼" - $1.00-1.50 2 yr 3" - $1.75-2.25
Installation Total:	2 x wholesale

References:
Wyman (1977)
Sunset (1979)
Robinson (1960)

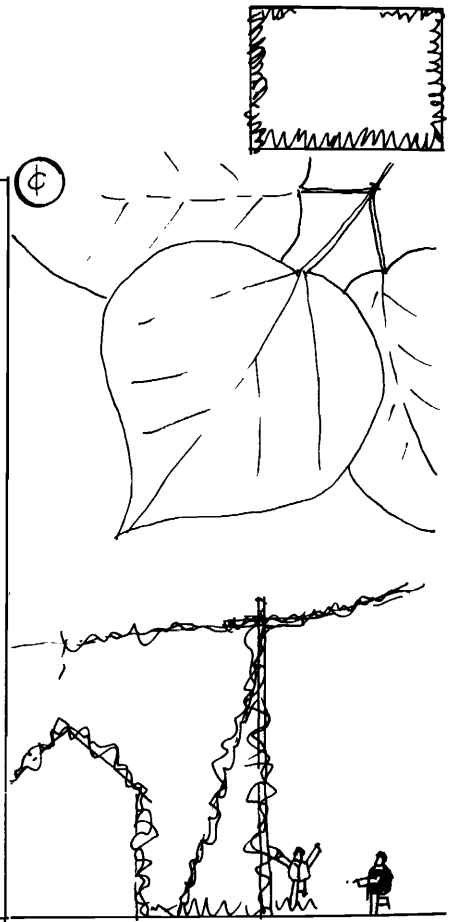
Notes:

- Typical spacing: 3-4' o.c. base of wall
- Yearly pruning away from windows
- Aerial rootlets grip walls (brick or masonry walls, not trellis, stucco or shingles)
- Branches in winter cover 25-30% of wall

Alt.- Parthenocissus quinquefolia (Virginia Creeper)

VINE

PUERARIA LOBATA (THUNBERGIANA) (KUDZU VINE)



Characteristics:		Requirements:	
Form:	Twining vine	Light:	Full sun to partial shade
Shade Density:	Very dense when established	Soil Texture:	Coarse to fine, well drained
Growth Rate:	Extremely rapid, 50' growth per year	Minimum Soil Depth:	18-24" for 2-3 years
Size at 5 Years:	Very large	Water:	Moist to drought-tolerant
Size at Maturity:	50-60'	Nutrients:	Tolerant
Seasonal Leafout:	Late spring (evergreen in warm climate)	Container Tolerance:	Short-term, 2-3 years in 24" container
Seasonal Leafdrop:	Early fall	Maintenance:	Low

Cost:	
Nursery Wholesale:	Not readily available Rooted cuttings grow rapidly
Installation Total:	--

References:
Wyman (1977) Perkins (1964) Robinson (1970)

Notes:

- Spreads by underground runners
- Out of control it will cover houses, pine trees, and telephone poles
- Support: loosely twining
- Rampant throughout south, can easily get out of hand
- Fastest vine in warmer climates
- This must be used with caution, not recommended in many locations

VINE

WISTERIA FLORIBUNDA (JAPANESE WISTERIA)

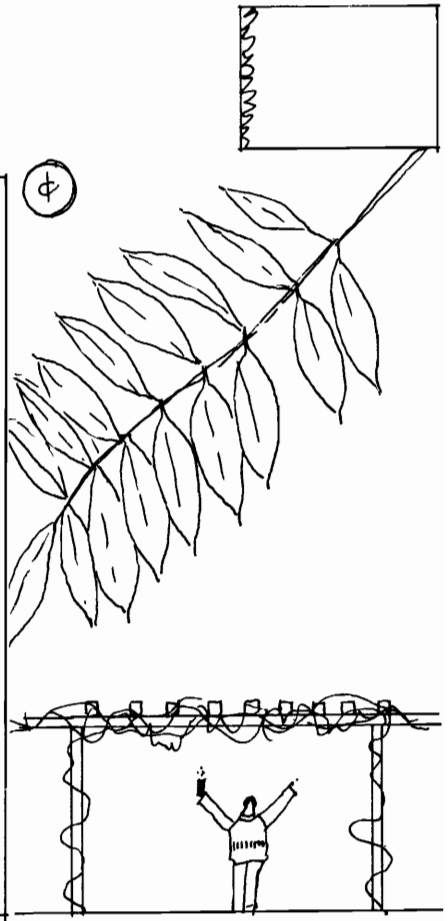
Characteristics:		Requirements:	
Form:	Twining vine	Light:	Full sun to partial shade
Shade Density:	Medium	Soil Texture:	Coarse to medium, good drainage
Growth Rate:	Slow to rapid	Minimum Soil Depth:	12-15"
Size at 5 Years:	15-25'	Water:	Moist to drought-tolerant
Size at Maturity:	30-40' covers 4-5 story building	Nutrients:	Prefers acid to neutral Add iron in alkaline soils
Seasonal Leafout:	Early spring	Container Tolerance:	Good, long-term
Seasonal Leafdrop:	Late fall	Maintenance:	Low

Cost:	
Nursery Wholesale:	2-3' cont $6-7 3-4' cont. $7.50-8.50
Installation Total:	4 yr heavy 8"-$12-13
Installation Total:	2 x wholesale
References:	Wyman (1977) Perkins (1964) Sunset (1979) Robinson (1960)

Notes:

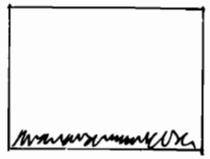
- Typical spacing: 5-10' o.c.
- Support: twining vine--heavy ties or frame to twine around
- Thin out yearly for desired form
- Few pests
- Outstanding flowers
- May either be grown as vines, shrubs, or trees

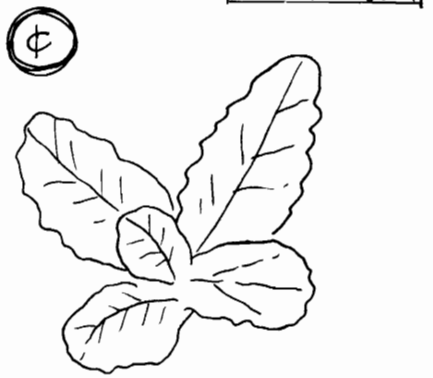
Alt. - Wisteria sinensis (7-13 leaflets)



GROUNDCOVER

AJUGA REPTANS (BRONZE AJUGA, CARPET BUGLE)



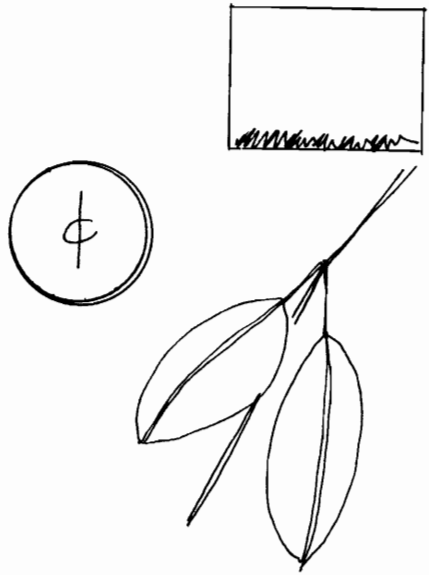


Characteristics:		Requirements:	
Form:	Prostrate--6-8" high	Light:	Full sun to partial shade
Shade Density:	Dense cover	Soil Texture:	Coarse to fine
Growth Rate:	Rapid	Minimum Soil Depth:	6-8"
Size at 5 Years:	Infill within one year	Water:	Moderate to moist
Size at Maturity:	4-6", solid cover	Nutrients:	Wide tolerance
Seasonal Leafout:	Evergreen	Container Tolerance:	Very good Long-term
Seasonal Leafdrop:	--	Maintenance:	Low

Cost:		Notes:
Nursery Wholesale:	2¼" pots, 40¢ each	- Typical spacing: 8-12" o.c. for infill in one year - Widely grown
Installation Total:	2 x wholesale	
References:	Sunset (1979)	

GROUNDCOVER

COTONEASTER DAMMERI (C. HUMIFUSUS) (BEARBERRY COTONEASTER)



Characteristics:		Requirements:	
Form:	Prostrate to 12" height, trailing	Light:	Full sun to partial shade
Shade Density:	Medium	Soil Texture:	Coarse to fine
Growth Rate:	Rapid, 12-18"/year	Minimum Soil Depth:	8-12"
Size at 5 Years:	Infill within 3 years	Water:	Moist (drought-tolerant when established)
Size at Maturity:	Mounds to 12-15"	Nutrients:	Tolerates poor soils
Seasonal Leafout:	Evergreen	Container Tolerance:	Very good, long-term
Seasonal Leafdrop:	--	Maintenance:	Low

Cost:	
Nursery Wholesale:	1 gal. cont. $2-3
Installation Total:	2 x wholesale

References:	
	Wyman (1977)
	Sunset (1979)

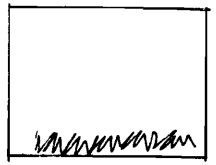
Notes:

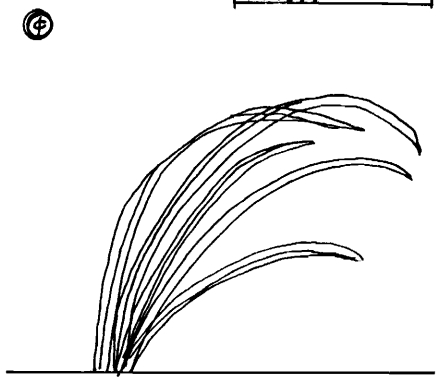
- Typical spacing: 18 to 30" o.c.
- Branches root
- Good for erosion control
- Trails 8-10' over walls
- Fire blight occasional
- Trim back at edges

Alt. - Cotoneaster lowfast
C. horizontalis
C. skogsholmen
C. microphylla

GROUNDCOVER

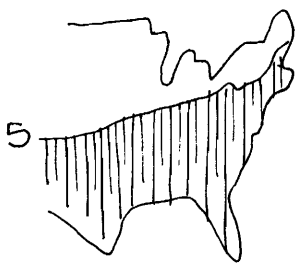
LIRIOPE MUSCARI (BIG BLUE LILY TURF)





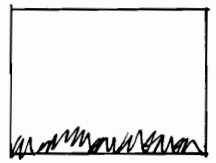
Characteristics:		Requirements:	
Form:	Clumping 12-18" high	Light:	Light to dense shade
Shade Density:	Medium	Soil Texture:	Coarse to medium
Growth Rate:	Rapid	Minimum Soil Depth:	4-6" depth
Size at 5 Years:	Infill in 12-18 months	Water:	Moist to moderate
Size at Maturity:	Solid cover 12-18" clumps	Nutrients:	Acid to neutral
Seasonal Leafout:	Evergreen	Container Tolerance:	Very good
Seasonal Leafdrop:	--	Maintenance:	Low

Cost:		Notes:
Nursery Wholesale:	1 gal. cont. $3-3.75	- Typical spacing: 12-18" o.c. - Cut back brown tips - Grass-like leaves Alt. - Ophiopogonum (Mondo Grass)
Installation Total:	2 x wholesale	
References:	Sunset (1977)	

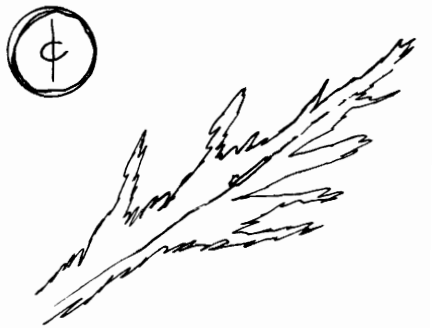


GROUNDCOVER

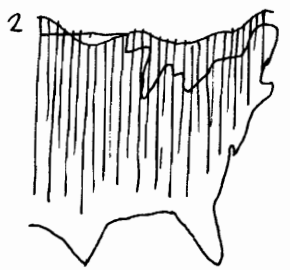
JUNIPERUS HORIZONTALIS (JUNIPER)



Characteristics:		Requirements:	
Form:	Prostrate 6-18" high	Light:	Full sun to partial shade
Shade Density:	Dense	Soil Texture:	Coarse to fine
Growth Rate:	Slow to moderate	Minimum Soil Depth:	12-18"
Size at 5 Years:	Infill within 3-5 yrs	Water:	Moderate to drought-tolerant
Size at Maturity:	6-18" solid cover	Nutrients:	Acid to alkaline
Seasonal Leafout:	Evergreen	Container Tolerance:	Very good, long-term
Seasonal Leafdrop:	--	Maintenance:	Very low

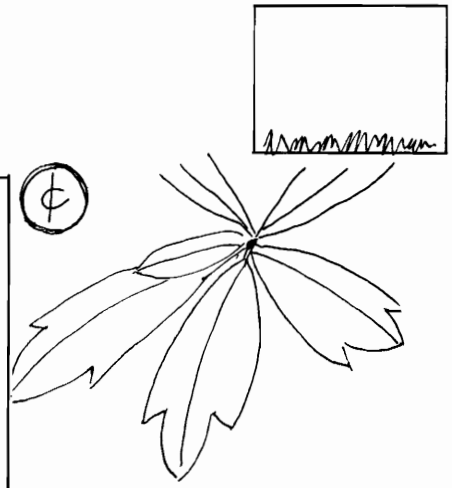


Cost:		Notes:
Nursery Wholesale:	1 gal. cont. $3-4 5 gal. cont. $12-15	- Typical spacing: 4-5' o.c. - Minor spray/insect problems
Installation Total:	2 x wholesale	Alt. - Juniperus sabina tamariscifolia J. conferta - Zone 5
References:	Wyman (1977) Sunset (1979)	Cultivars - "Bar Harbor" "Andorra"



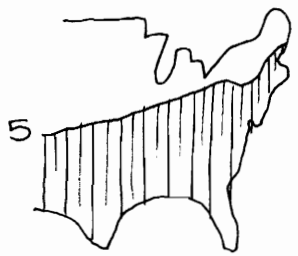
GROUNDCOVER

PACHYSANDRA TERMINALIS (PACHYSANDRA or JAPANESE SPURGE)



Characteristics:		Requirements:	
Form:	Spreading 6-9" high	Light:	Full sun to dense shade
Shade Density:	Dense	Soil Texture:	Coarse to medium
Growth Rate:	Slow to moderate	Minimum Soil Depth:	4-6" depth
Size at 5 Years:	Infill within one year	Water:	Moist to moderate
Size at Maturity:	6-10", solid cover	Nutrients:	Acid
Seasonal Leafout:	Evergreen	Container Tolerance:	Very good, long-term
Seasonal Leafdrop:	--	Maintenance:	Low

Cost:		Notes:
Nursery Wholesale:	2¼" pots - 35-50¢ ea.	- Typical spacing: 8-10" o.c. - Underground stolons - Among best groundcovers for partial shade - Widely planted
Installation Total:	2 x wholesale	

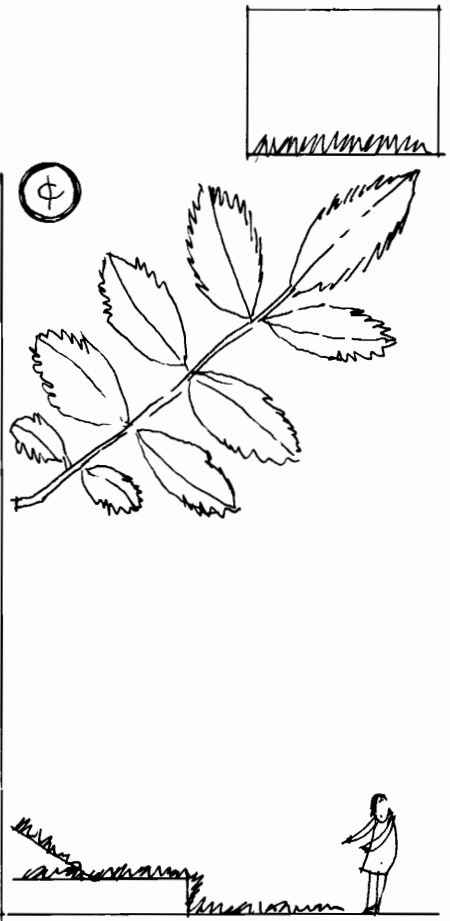


References:

Sunset (1979)
Wyman (1977)
Robinson (1960)

GROUNDCOVER

ROSA WICHURAIANA (MEMORIAL ROSE)



Characteristics:

Form:	Trailing 12-15" high
Shade Density:	Medium
Growth Rate:	Rapid, 8-10'spread/ year; slow to start
Size at 5 Years:	Infill within 5 years
Size at Maturity:	Large spread 4-8" height
Seasonal Leafout:	Early spring
Seasonal Leafdrop:	Mid-fall

Requirements:

Light:	Full sun
Soil Texture:	Coarse to fine, well drained
Minimum Soil Depth:	15-18"
Water:	Moist to moderate
Nutrients:	Poor soils
Container Tolerance:	Very good
Maintenance:	Low

Cost:

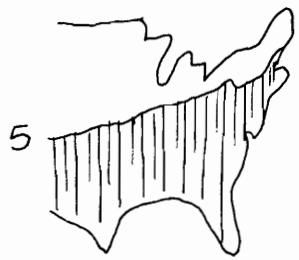
Nursery Wholesale:	12-18" BR, $.80-1.25 2 yr,2-3' BR, $1.30-2.00
Installation Total:	2 x wholesale

References:

Sunset (1979)
Wyman (1977)
Robinson (1960)

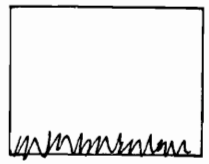
Notes:

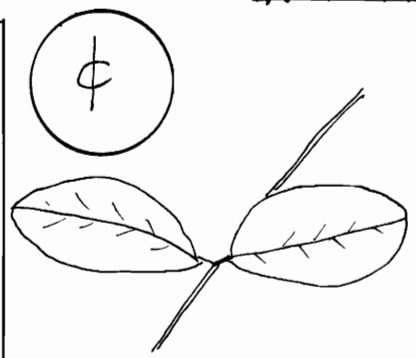
- Typical spacing: 3-4' o.c.
- General thinning only to remove dead wood
- Erosion control and bank cover, stems root in moist soils
- White summer flowers



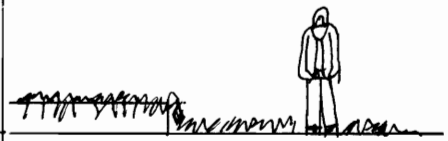
GROUNDCOVER

VINCA MINOR (PERIWINKLE or MYRTLE)

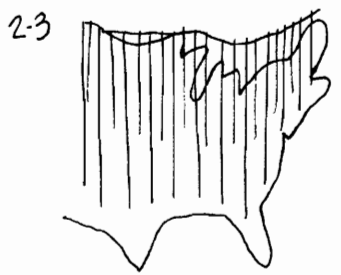




Characteristics:		Requirements:	
Form:	Prostrate 4-6" high	Light:	Full sun to dense shade
Shade Density:	Dense cover	Soil Texture:	Coarse to fine
Growth Rate:	Moderate to rapid 12-18"/year	Minimum Soil Depth:	4-6"
Size at 5 Years:	Infill in 2 years	Water:	Moist to drought-tolerant
Size at Maturity:	4-6", solid cover	Nutrients:	Very low requirements
Seasonal Leafout:	Evergreen	Container Tolerance:	Very good
Seasonal Leafdrop:	--	Maintenance:	Very low once established



Cost:		Notes:
Nursery Wholesale:	2¼" pots, $.40-.50 ea.	- Typical spacing: 12-15" o.c.
Installation Total:	2 x wholesale	Cultivars - "Bowles" - larger clumps.
		Alt. - Vinca major - taller, only grown in warmer climates



References:

Wyman (1977)
Robinson (1960)

SELECTED PROJECTS

Plants have often been combined with buildings, though usually for aesthetics rather than energy conservation. A large body of built projects exists: flat roof gardens, terraced roof gardens, and balcony and bris-soleil planters. These existing projects are a resource for anyone wishing to use plants for passive cooling, since they have addressed the structural and maintenance problems involved in putting plants on buildings. Much can be learned from their success and failure. Selected projects are therefore listed below. Since parking lots account for much of the pavement required near and around buildings, projects which have used trees and grass pavement are also listed. In most cases, these were designed to improve the appearance of parking lots, but they have the additional benefit of preventing heat gain at the ground surface.

Roof Gardens: Commercial/Large-Scale

— Oakland Museum; Oakland, California (D. Kiley, Landscape Architect).

— Kaiser Headquarters; Oakland, California (T. Osmundson, Landscape Architect).

— Weyerhauser Headquarters; Tacoma, Washington (SWA Group, Landscape Architects).

— Constitution Plaza; Hartford, Connecticut (Sasaki Associates, Landscape Architects)

— Place Bonaventure; Montreal, Canada (Sasaki Associates, Landscape Architects)

— Seattle Freeway Park; Seattle, Washington (Lawrence Halprin, Landscape Architect).

Planted Roofs: Residential Scale

— Houses at Rowan Lane; Capetown, South Africa (A. and A. de Souza Santos, Architects).

— Wells' Architectural Office; Cherry Hill, New Jersey (Malcolm Wells, Architect).

— Solaria; Philadelphia, Pennsylvania (Malcolm Wells, Architect).

Terraced Gardens

— Promentory Point; Newport Beach, California (SWA Group, Landscape Architects).

Bris Soleil Planters

— Apartments, 2 Scott Road; Capetown, South Africa (A. and A. de Souza Santos, Architects).

Parking Lot: Tree Canopy

— Greenville-Spartenburg Airport; South Carolina (SOM Architects)

— Nut Tree Parking Lot; Fairfield, California

— Polariod Company; Waltham, Massachusetts

— Willows Shopping Center; Concord, California (SWA Group, Landscape Architects)

— State Lots; Sacramento, California

— A. D. Little Parking Lots; Cambridge, Massachusetts

Parking Lot: Grass Pavement

— Security Pacific Lot; Los Angeles, California

— Canal Street; New Orleans, Louisiana

— Gulf Islands National Seashore; Gulf Breeze, Florida

— Concord Pavilion; Concord, California (SWA Group, Landscape Architects)

— City Parking Lot; Fort Lauderdale, Florida

— Emory University; Atlanta, Georgia

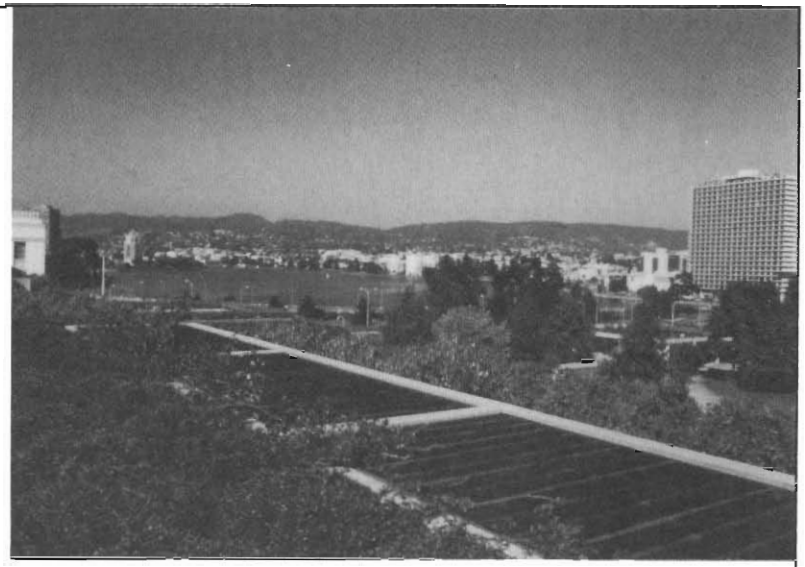
— Dayton Green Parking Lot; Dayton, Ohio

— Tacoma Pavilion; Tacoma, Washington (Lawrence Halprin, Landscape Architect).

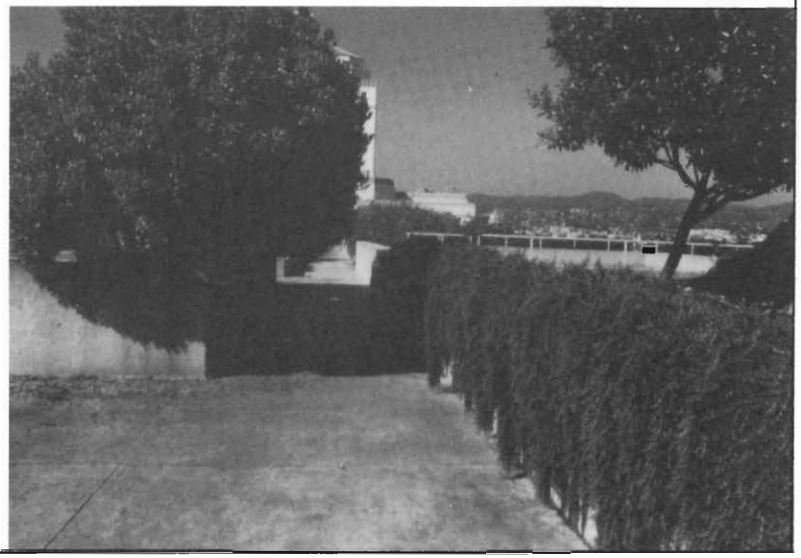
— Sweet and Associates; Schenectady, New York

— R. J. Reynolds Office Building; Charlotte, North Carolina

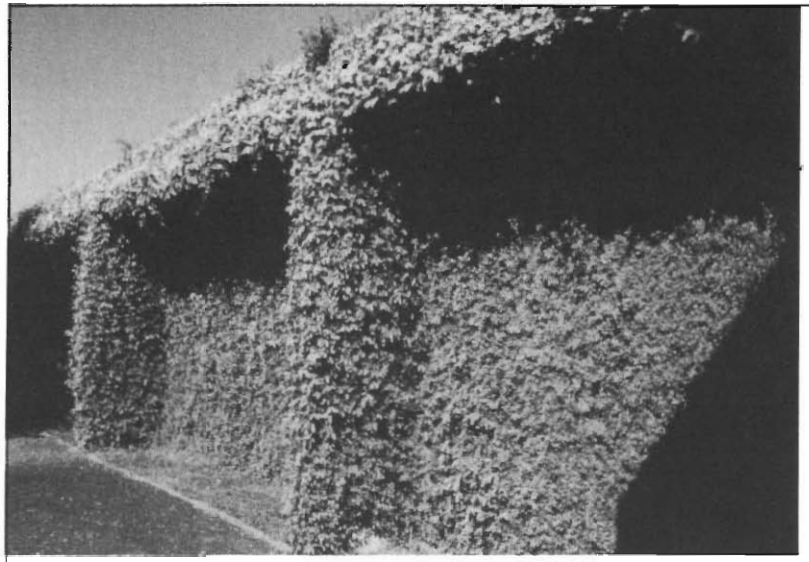
— U.S. Naval Academy; Annapolis, Maryland (Zion and Breen, Landscape Architects)



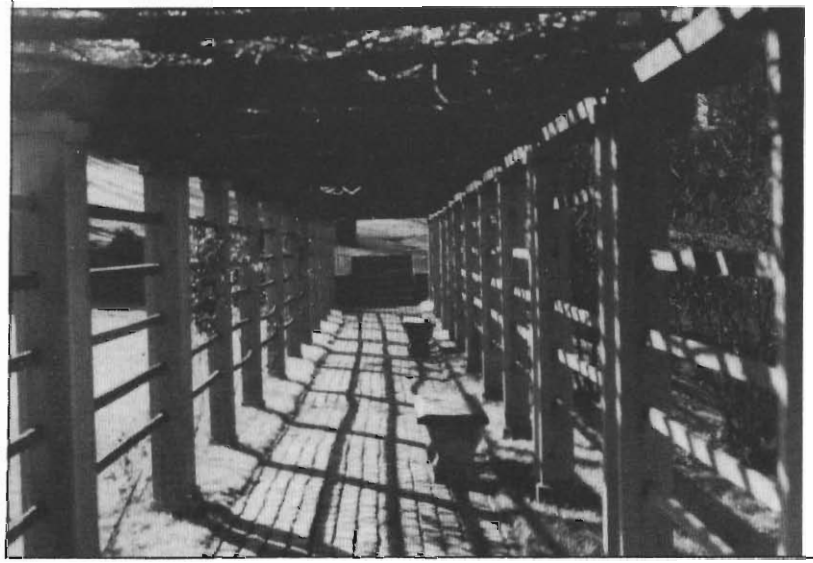
1. Roofdeck, Oakland Museum, Oakland, California.



2. Roofdeck Planters, Oakland Museum, Oakland, California.



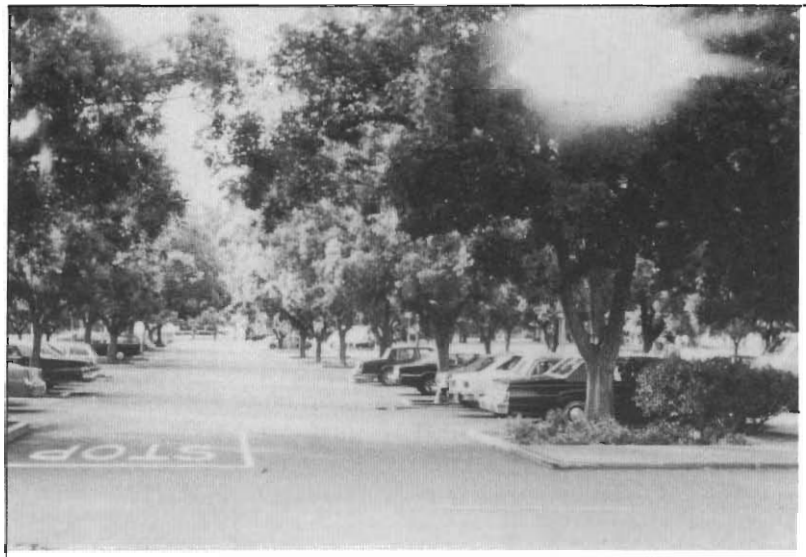
3. Vine Wall, Oakland Museum, Oakland, California.



4. Vine Trellis, Dumbarton Oaks, Washington, D.C.

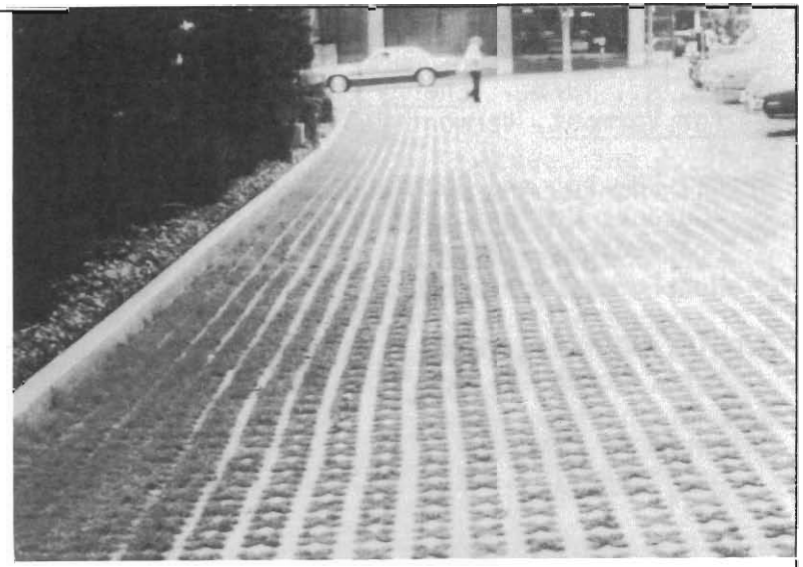
5. Tree Screen, Portland, Oregon.

6. Tree Screen, Flint, Michigan.

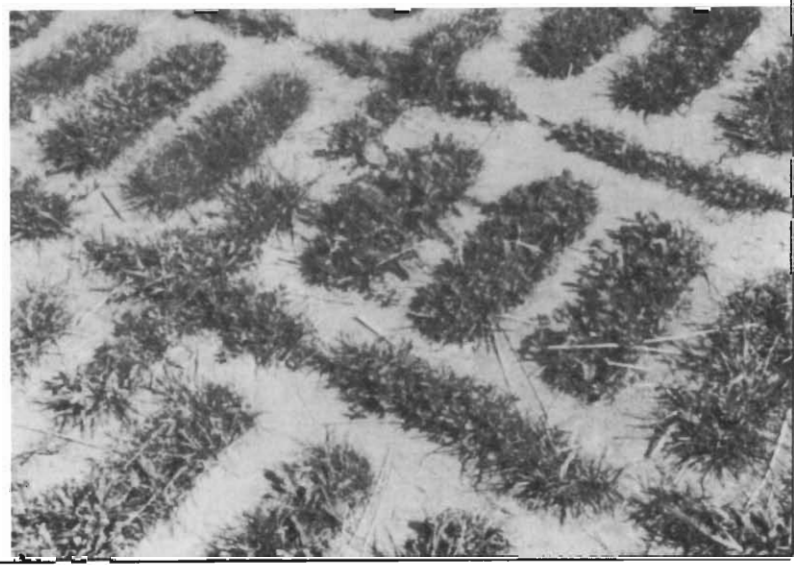


7. Nut Tree Parking Lot, Fairfield, California.

8. State Parking Lots, Sacramento, California.



9. Grass Pavement Parking Lot, Security Pacific, Los Angeles, California.



10. Grass Pavement.

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