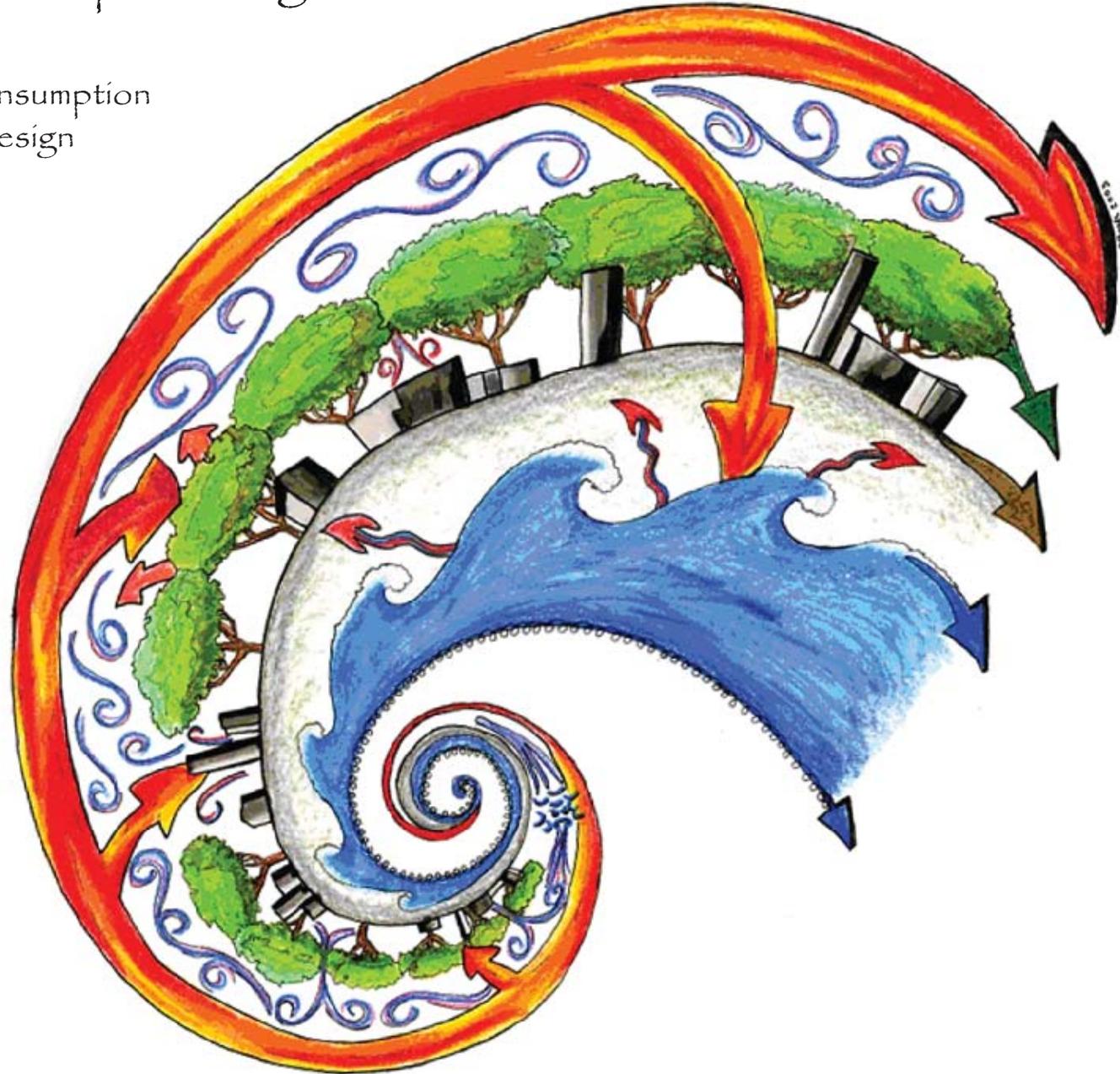


# Passive Solar Landscape Design

Its Impact on Fossil Fuel Consumption  
Through Landscape Design



Robin Wiatt Boelt

Thesis submitted to the faculty of  
the Virginia Polytechnic Institute and  
State University in partial fulfillment  
of the requirements for the degree of

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in  
Landscape Architecture

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Design, solar, microclimate

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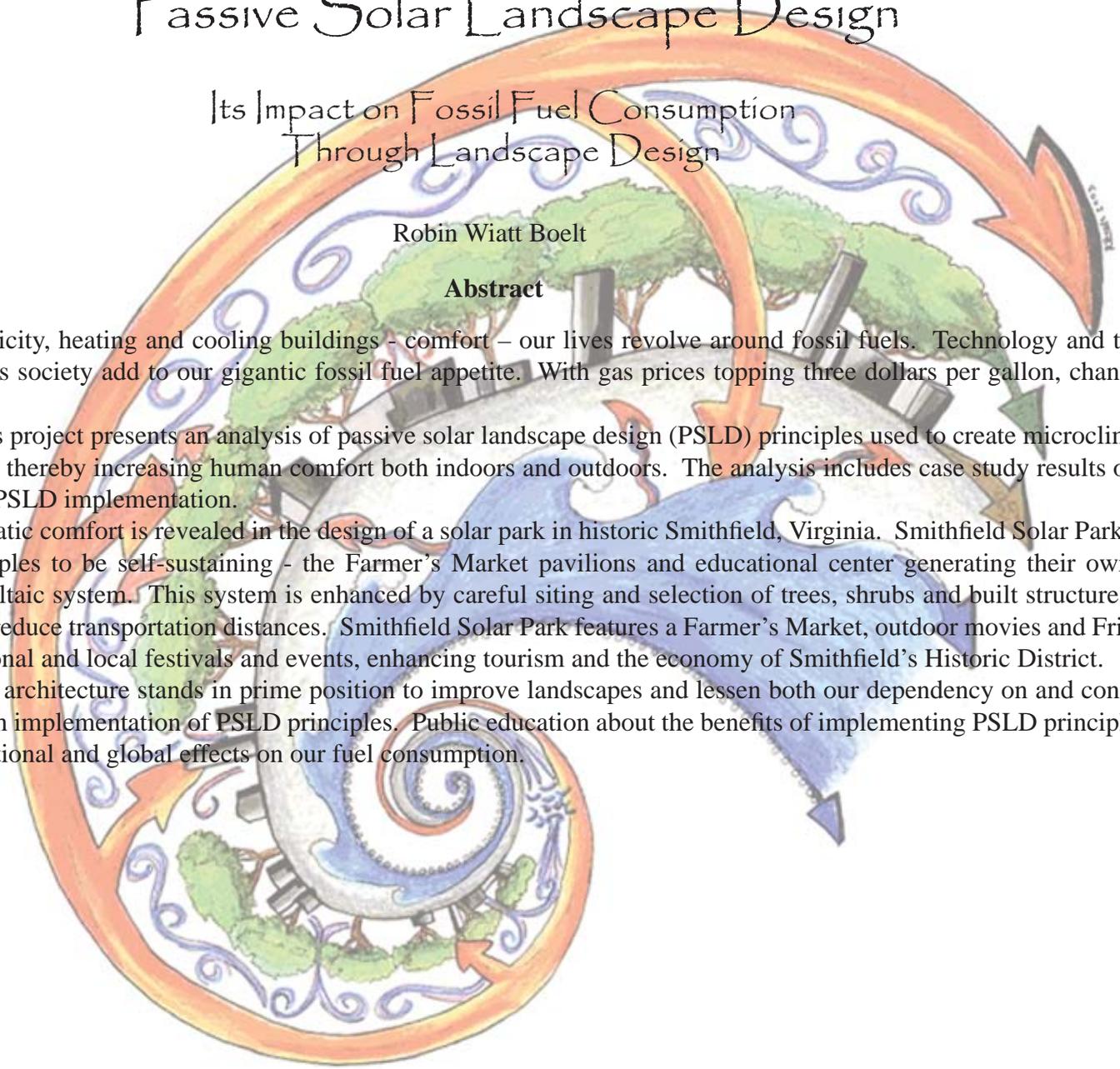
### Abstract

Gas, electricity, heating and cooling buildings - comfort – our lives revolve around fossil fuels. Technology and the demands of living in today's society add to our gigantic fossil fuel appetite. With gas prices topping three dollars per gallon, changes must be made.

This thesis project presents an analysis of passive solar landscape design (PSLD) principles used to create microclimates within the landscape, and thereby increasing human comfort both indoors and outdoors. The analysis includes case study results of fossil fuel consumption and PSLD implementation.

Microclimatic comfort is revealed in the design of a solar park in historic Smithfield, Virginia. Smithfield Solar Park is designed with PSLD principles to be self-sustaining - the Farmer's Market pavilions and educational center generating their own electricity through a solar voltaic system. This system is enhanced by careful siting and selection of trees, shrubs and built structures and use of local materials to reduce transportation distances. Smithfield Solar Park features a Farmer's Market, outdoor movies and Friday Cheers, and will host regional and local festivals and events, enhancing tourism and the economy of Smithfield's Historic District.

Landscape architecture stands in prime position to improve landscapes and lessen both our dependency on and consumption of fossil fuels through implementation of PSLD principles. Public education about the benefits of implementing PSLD principles can have local, regional, national and global effects on our fuel consumption.



This thesis project and book are dedicated to my parents, Reba and Robert Wiatt.



## Acknowledgements

I knew while I was taking my qualifying classes at Lewis Ginter Botanical Gardens through George Washington University that I wanted my thesis project to revolve around the sun, just as our Mother Earth does. I had no idea though, of the sheer joy, exhaustion, exhilaration, frustration, enlightenment, lack of sleep and mountain of work that would befall me along my journey through the design process. Family and friends' steadfast support and encouragement to 'stay the course' through my excitement and rantings has kept me afloat through it all, and, for that, I will always be grateful.

First of all, I want to thank you Terry for everything! You pushed me when I needed it, guided me when I was uncertain and, above all, expanded my thinking process as a designer. Caren, what can I say? Your endless energy, encouragement, understanding and, most of all - friendship is priceless. I value it more than you know. I can't thank you enough for being there and teaching me so much! Dean, thanks for your insight into my design, for your critiques and understanding. Paul Emmons, your insightful desk crits and guidance led to my final design - I will always remember you and strive to think outside the box.

Thanks to all my teachers and fellow students at the GWU Lewis Ginter program - I really enjoyed learning with you and from you. Thanks, Leigh Duke, for your newsletter, from which I discovered WAAC. As for all my WAAC classmates, I have learned so much from you all, and value your friendship.

Thanks go out to my husband for keeping our household in Powhatan afloat for the two years that I have lived here in Alexandria - and to my Mom and Dad for a lifetime of love, patience and good times! My friends - Toni, Montie, Gael, Jerry, Reba and Cindy - your support, emails and phone calls really were my foundation during my journey - I dearly love you all.

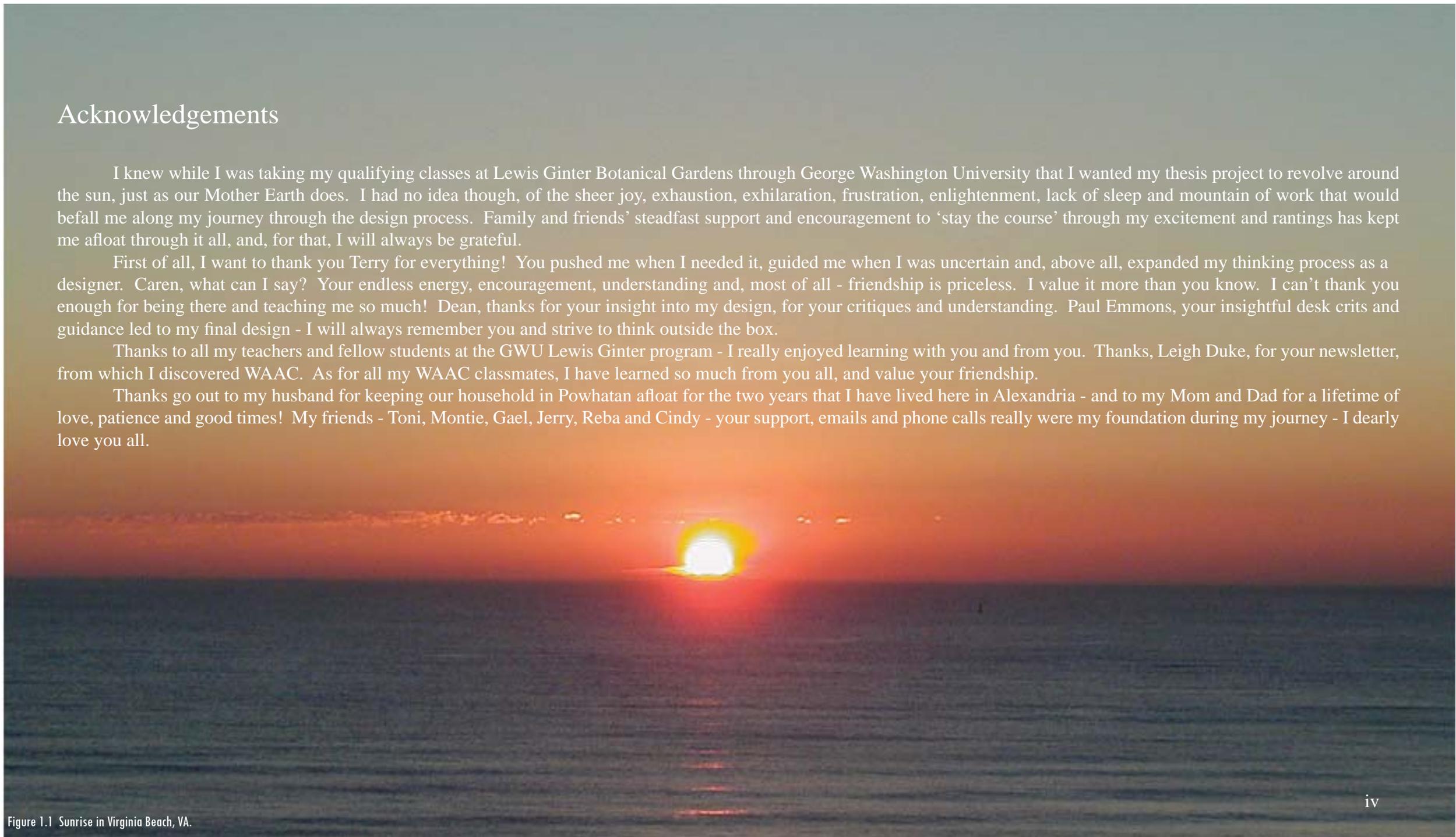


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Figure 1.2 Sunset in Smithfield, VA.

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## Part One: Thesis Position

- Introduction
- Earth
- Wind
- Fire
- Water
- How a site is used
- PSLD principles

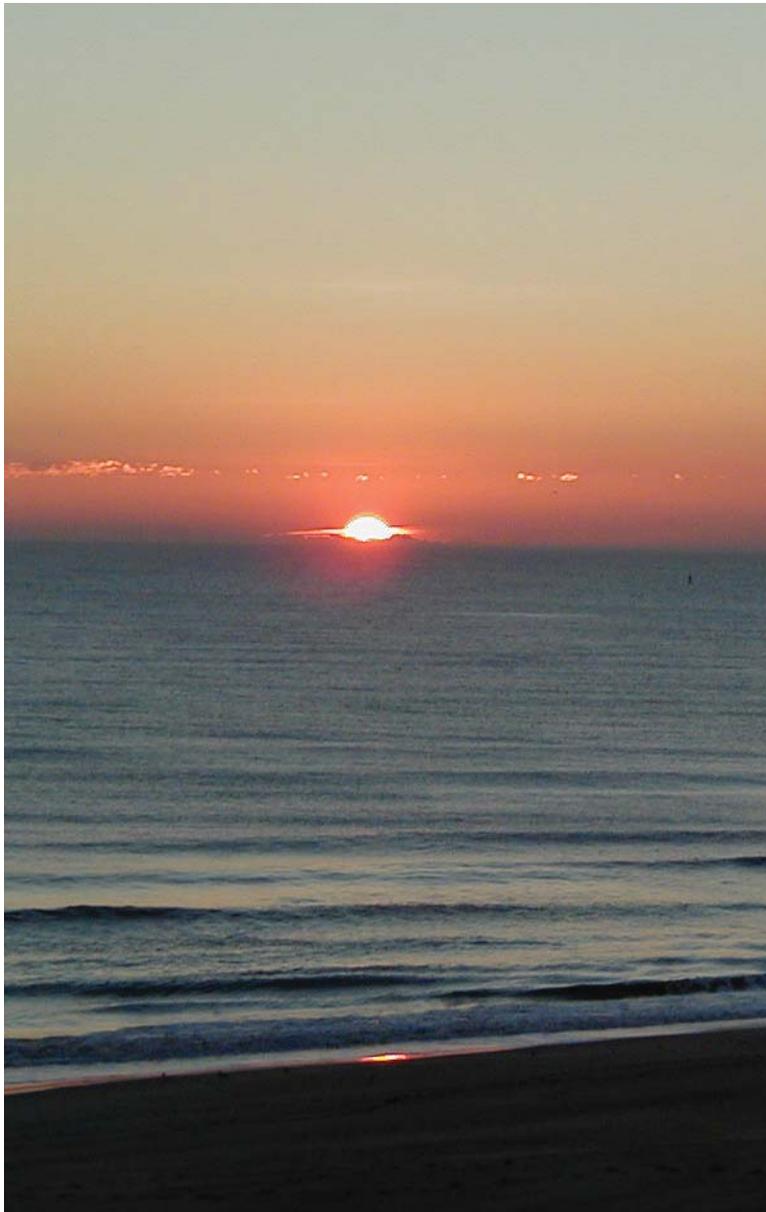


Figure 1.5 Sunrise in Virginia Beach, VA.

*My father rode a camel. I drive a car. My son  
flies a jet airplane. His son will ride a camel.*  
– Saudi Proverb (Schaeffer 2005)

It is my objective to demonstrate that through passive solar landscape design (PSLD) landscape architects can use the warmth of the sun, the cooling and warming of air currents and water, and shade to create microclimates which make the outdoors more comfortable and usable year around. People will enjoy their own landscapes more, lessening travel to other places. We can both shade and allow solar energy into buildings to lessen heating and cooling costs. These actions will substantially lower our dependency on fossil fuel consumption.

My position paper focuses on the principles of PSLD and how it impacts human comfort and fossil fuel consumption. The literature review includes two related theses as well as book and internet sources. The Farmer’s Market in Alexandria, the Kitchen Garden at Mount Vernon and the grounds of the National Zoo are case studies of passive solar landscape architecture principles. Each site relates microclimate effects of passive solar design to its function, human and animal comfort levels and fossil fuel consumption.

---

The peak of the ‘Age of Oil’ is expected to be reached between 2006 and 2015. At that point, 50% of the world’s known oil reserves will have been consumed. The last oil field holding in excess of 500 million barrels of oil was found in 2002. Given the extensive global search, Geologists believe that we may never find another one. (Schaeffer, 2005)

In the fall of 1973, an international energy crisis resulted from Israel’s “Six Day War”. Arab oil-producing nations raised

the price of oil and initiated an embargo, stopping oil shipments to the United States, causing a U.S. energy crisis.

Coal, natural gases and oil are called ‘fossil fuels’ because they are formed from the fossilized remains of prehistoric plants and animals. One by-product of burning fossil fuels is carbon dioxide – one of the principal causes of global warming. Scientists began recording average annual temperatures in 1866, and the sixteen warmest years have all occurred between 1980 and 2005. The first and second warmest years were 1998 and 2002, respectively.

How can landscape architects reduce our use of fossil fuels? We use fossil fuel generated electricity, natural gas and oil to heat our homes and businesses, drive gas-guzzling cars and SUVs and manufacture plastics. Architects, designers and builders rarely consider all aspects of the environment for all that it offers. Landscape architects can play an important role minimizing this problem by utilizing PSLD principles.

PSLD not only makes outdoor spaces more comfortable for people year-round, it also can dramatically reduce fossil fuel used to heat and cool buildings. PSLD is an environmentally sensitive way to design the outdoor space by going back to the basics - back to the camel - taking advantage of the characteristics of earth, wind, fire and water. It takes advantage of these natural characteristics to help maintain a comfortable outdoor environment for people and help heat and cool buildings, while operating with little or no mechanical assistance.





Figure 1.6 Kitchen Garden at Mount Vernon, VA. The brick wall absorbs and radiates solar radiation into the garden, extending the growing season by more than one month. The picket fence protects the garden from damaging winds and animals.

PSLD principles are based on using shade from plantings, built structures and other buildings to cool spaces in the summer months, and maximizing the sun's energy to warm spaces in the cold months. Wind is another aspect to consider when designing for comfort. The design principles take advantage of local breezes throughout the changing seasons by directing and channeling cooling breezes in the summer and blocking them in winter through landscape plantings and built structures or windbreaks. Water is used as a cooling element in the summer, especially when coupled with breezes. Water has potential too, as it warms slowly and slowly releases the heat back into the site.



Figure 1.7 Sheltered resting bench at Dumbarton Oaks. The earth and stone absorb and radiate heat during cold weather and it is a shaded, earth-cooled area during hot weather.

## Earth

From earliest civilization, man has used earth, wind, fire, and water to make his existence more comfortable. Empedocles and Plato postulated that these were the four basic elements of nature. In Rome, the Cryptoporticus subterranean, a long, narrow room built into the earth, offered a cooling respite from the summer sun. In medieval gardens, banks of earth at seating height were often planted with grass, flowers or herbs which released pleasant fragrances when crushed. In Baroque and later picturesque landscapes, grottoes constructed to imitate natural caves were open to the prevailing summer winds. Cool seats were ideally situated above a body of water with their backs open to the prevailing winds. Covered or pruned arbor walks provided shade with a living cover for pedestrians, while directing cooling breezes. The Villa Gamberaia in Italy is an example of this. (Sullivan, 2002)

**Vegetation:** A bosco is an outdoor room with walking paths and resting areas, densely planted in a geometric pattern with trees, preferably evergreen, that is normally sited on the north side of the garden or building. This geometric pattern ensures that each tree has an equal amount of sunlight, producing large amounts of oxygen while absorbing carbon dioxide. The bosco shields the garden from the cold winter winds, while allowing the warming solar energy into the site. It absorbs solar radiation during the day, radiates it back at night and reduces the ambient temperature at ground level within, due to the increased humidification of the air from the tree leaves.

PSLD uses these same principles today. Although plantings may not be as large, geometric groves or windbreaks of evergreen trees are routinely planted to block the cold winter winds from a site or building. There is an area on the leeward side of a windbreak that is calm because the wind coming over the windbreak travels above it as it eventually makes its way back to earth. The higher and more dense the windbreak, the larger the insulated area will be. The vegetative mass should be three times the structural mass of the building. This insulating protection helps reduce fossil fuel consumption by decreasing the heating load for the building. The garden area will also be more comfortable year around.



Figure 1.8 Wind blowing through THE GATES in Central Park.



Figure 1.9 Daschund weather vane and American flag show both wind direction and relative velocity at a Virginia Beach home.

## Wind

Early builders realized that the garden was an ideal place to escape the oppressive heat of interiors of buildings. The force, direction and time of year that winds and breezes blow dictates much of the perceived comfort level. Shady areas are naturally cooler and more comfortable on hot days, even more so when paired with moving air. Air currents can be blocked, channeled, directed and accelerated with landscape elements. Cool seats, cool walks, pergolas and porches were developed by early designers and are still used.

Cool seats provide comfortable places to sit in the shade and rest during hot weather. Built with low or open-backed, they were usually situated under trees to catch cooling summer breezes. Siting them above natural or man-made water makes them even more functional as a landscape feature. Cool walks are narrow pathways shaded by evenly spaced trees along their edges. Trees are often used to direct views. Breezes channeled along these pathways enhance the paths' cooling capabilities.

Pergolas and arbors are vine-covered structures used for shading sitting areas and walks. The pergola is an elaborate version of the rustic arbor. Pergolas have strong columns to support a framework of cross members which vines grow along to shade the area. The vines increase awareness of the changing seasons as they fruit, change color in fall and drop their leaves for winter. In addition to providing shade, arbors and pergolas channel breezes under their horizontal framework to enhance outdoor enjoyment and to cool the buildings to which pergolas are often attached.

Careful siting of landscape plants creates passive microclimates, which can result in year around use of our garden areas. Evergreen and deciduous trees and plants can block, redirect or allow breezes and wind into a site, depending on the density, shape and presence of their foliage.



Figure 1.10 Solar shingles now replace the bulky, upright solar collectors that were a consumer's only choice in the 1990's.

## Fire

The sun is the energy source for almost all life on earth. Cave dwellers knew about the warming properties of the sun. Solar energy and orientation were considered in building orientation and siting as early as 36 BC, when Varro identified the southeast facing hillside as the optimum site for a villa. Pliny the Younger and Varro's letters formed the basis for site design, and these principles are still used today.

Humans and animals seek its warming power on cold days and relief from the same power through shade during hot weather. Sunlight is vital for physical and psychological health, and is the foundation of PSLD.

In the landscape, hot seats and warm walks offer people the opportunity to bask in the winter sun's warming rays. Seats and walks facing the winter sun, and made of thick slabs of stone absorb and radiate the heat outward. (Sullivan, 2002) The high seat backs of hot seats deflect cold winter winds as the benches collect and radiate solar energy. Warm walks and terraces set into south facing walls or earth terraces receive direct sunlight. Constructed of stone, they radiate heat as the benches, optimizing solar gain. A width of four feet is optimum for keeping pedestrians close to the sun-warmed stone walls.

Sunlit terraces enclosed on three sides block cold winter winds and open south facing sides take advantage of warming solar energy. These configurations create heat traps that are comfortable long after open terraces would be uncomfortably cold. In addition to their winter characteristics, terraces create their own microclimates by catching cooling spring and summer breezes.

PSLD uses strategically placed trees and shrubs to shade buildings from the intense summer sun, while allowing the warming solar energy to come through to the building during the winter. Carefully sited deciduous and evergreen trees planted on the north, east and west sides of a building will block both the hot afternoon sun in the summer, and the cold winds in the winter, dramatically lowering fossil fuel consumption through heating and cooling the building.



Figure 1.11 The water wall in Paley Park, New York cools the area, drowns out city noise and is beautiful to watch.



## Water

Water is needed to sustain life and has been a central design element in many gardens throughout history. As it cools hot winds and its surrounding environment, water also provides great visual and sensual comfort. Water falling onto or running through a site can be collected and stored in cisterns, channeled and diverted through canals for irrigation, and used for both placid and active water devices. Development of these systems provides greater access to water, allowing larger communities of people to inhabit an area and more elaborate gardens to be built.

Cisterns have been used to store water since medieval times. Located underground and away from the heat of the sun, water stays cool and does not evaporate. Vignola designed the Palazzo Farnese in Caprarola, Italy around a cistern (Sullivan, 2004). In Vignola's time, cisterns were frequently located at a high point of the garden and decorated as a focal point. Water traveled through runnels into the central axis of the garden and then on to various water features.

Garden irrigation occurs through many means. For centuries, blanket watering has been achieved by elevating the walkways as dams to hold rain or irrigation water on site. The most efficient method of irrigation, however, was the use of "condensing jars", which were the precursor to today's drip irrigation. Condensing jars were earthenware jars set into the earth between plants with just the rim protruding above the soil. The jars were filled seeped water into the soil through the porous clay. Evaporation was all but eliminated.

Large pools of placid water irrigate gardens during drought and cool the areas by creating microclimates. The pools capture the runoff from streams and springs, and are a source of both visual and sensual pleasure. In hot weather, the large surface area of these pools creates large volumes of humidified air, which decreases ambient temperature. To retain this humidified air layer, trees with broadly sweeping horizontal

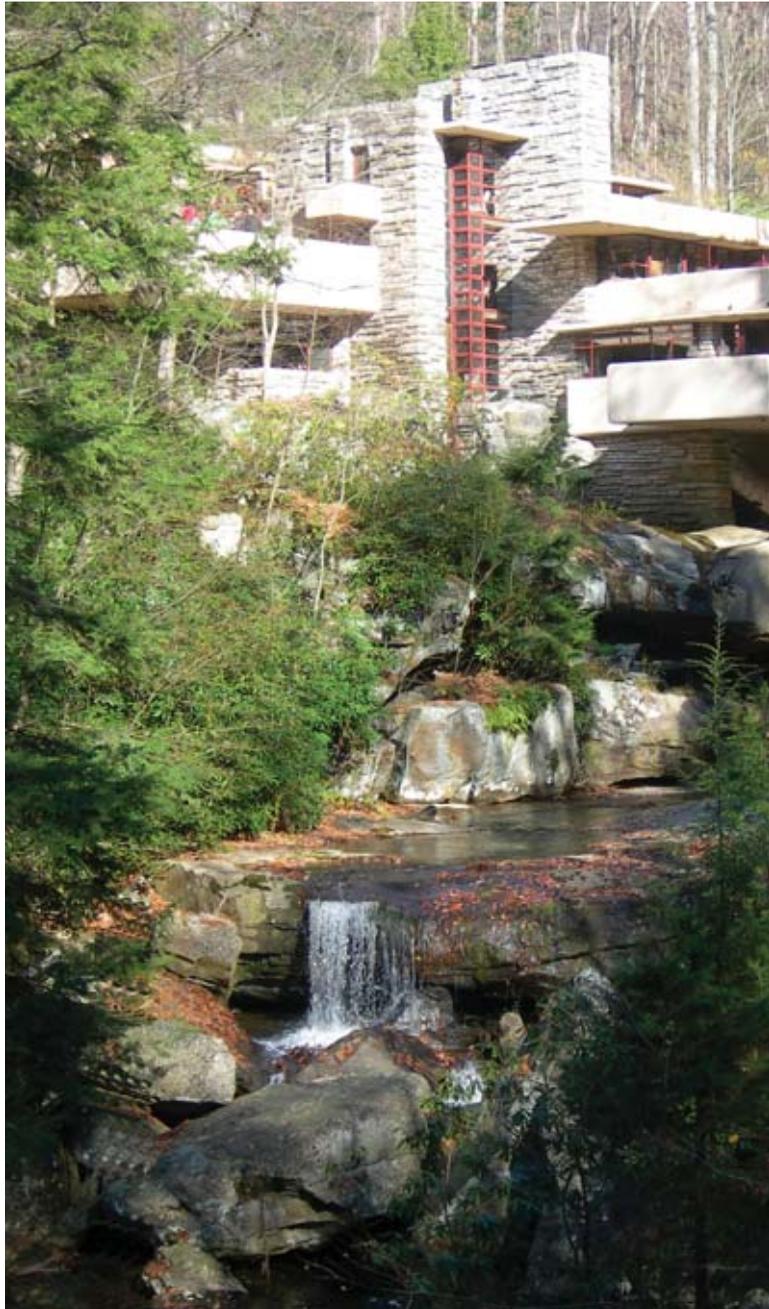


Figure 1.12 Cooling water and warming sun at Frank Lloyd Wright's Falling Water in Bear Run, Pennsylvania.



Figure 1.13 Wall fountain sheltered by a purple wisteria-covered trellis at Dumbarton Oaks.

branches were planted alongside the banks to keep the pool shaded.

Landscape architects can use water in many ways in the garden. Placid water, from the size of bird baths to reflecting pools conveys a sense of peacefulness. Moving water, both natural and man made, provides untold pleasures through light reflection, motion and sounds, as well as psychological relief with associations of plenty, especially appreciated in arid climates. As with placid water, it humidifies the surrounding air and lowers the ambient temperature, making the site more enjoyable for inhabitants in hot weather. The moisture in evapotranspiration cools the surrounding air and helps decrease heating and cooling loads on buildings. These benefits lower the consumption of fossil fuels by lowering the use of heat and air conditioning in buildings and decreasing travel because people will spend more time in their own landscapes.

Water is the single element that holds all of life in its droplets. A single drop may germinate a seed, while a river will sprout a city. Landscape architects can utilize the properties of water in PSLD to decrease fossil fuel consumption while maximizing the garden experience. This can be achieved through decreasing the ambient temperature and increasing humidification of the air in hot weather, which provides sensual and psychological pleasure.

PSLD uses the energy and characteristics of earth, wind, fire and water in harmony to create microclimates for human comfort. Microclimatic comfort is maximized when these four elements are considered in the landscape together and limited benefits result if they are used separately.



Figure 1.14 A good example of properly utilizing both landscape and portable shade structures for the comfort of inhabitants. Dumbarton Oaks Symposium WAAC attendees.

## How A Site Is Used

Necessary and optional behaviors occur in any outdoor spaces. Necessary activities are more or less compulsory, requiring people to participate. Optional activities are ones in which people will participate if there is a wish to do so, and if time and place make it possible. Most outdoor activities are considered to be ‘climate dependent’. Social activities are those that depend on the presence and participation of others in the public space (Gehl 1980). (Warner 1991)

The activities on any site can be influenced by PSLD and the manipulation of the four basic elements. Landscape architects must blend the principles of PSLD with the intended use of the particular site in order to achieve the goal of lowering fossil fuel consumption. If either intended use or psld principles are ignored, the site will not be complete, and the goal is unobtainable.

### Human comfort

According to Warner, William Whythe’s study, “*The Social Life of Small Urban Spaces*”, reported the factors that influence use of public plazas: food, water, activity, seating and sunlight. Wind also greatly affects people’s use of outdoor places. This is evidenced by the following quotation:

*Wonderfully designed plazas in San Francisco and other cities, that included many of the Whythe’s criteria to attract users, remain unused due to being windswept or lacking sufficient solar insolation to insure thermal comfort. (Warner 1991)*



Figure 1.15 The area under a tree canopy can be up to eight degrees cooler than the surrounding area.

Thermal comfort is the state in which a person expresses satisfaction with the thermal environment. In other words, they would neither like it cooler nor warmer. If a person is thermally comfortable, they may stop and enjoy what a site has to offer. If they are uncomfortable, they are likely to pass through on their way to another place.

Many factors affect how comfortable people are in the landscape. They include temperature, amount and type of precipitation, humidity, light, shade, wind, shelter, footing, access, and security. You cannot satisfy every person in your public space in every way, so you must seek to attain 'optimal' thermal comfort – the conditions where the most people are in their thermal comfort zone. (Warner 1991)

Givoni (1981) noted that at air temperatures of 67-77°F humidity does not affect physiological and sensory responses; at temp above 77°F with humidity in excess of eighty-five percent, one feels noticeable clamminess and dampness. Relative humidity between thirty and eighty-five percent is not noticeable. (Song 1987)

There are three temperature measures that affect human comfort levels: the ambient temperature, the sensible

temperature and the mean radiant temperature.

Ambient temperature is the temperature of the air surrounding an object. The presence of water on the skin can cool the body due to loss of heat energy to the water during evaporation. During very humid conditions this evaporative process is greatly reduced due to the amount of water vapor already in the atmosphere. As a result, cooling is reduced and the sensible temperature (the perceived temperature) may actually be warmer than the surrounding air temperature. Sensible temperature in warm weather is called the Heat Index. The mean radiant temperature (MRT) is a very important comfort variable. The MRT is the temperature of the surrounding surfaces, or the average of all the surrounding surfaces in a given area. Evapotranspiration is the loss of water from the soil both by evaporation and by transpiration from plants.

Climatic factors have a great impact on not only the PSLD itself, but also on how the design will decrease heating and air conditioning costs, and on the comfort of the people who come into the space. Different climates will shift emphasis from and towards different factors. For example, a

dry, arid area will not have a great emphasis on humidity, but will on air circulation and shade. Climatic factors include:

- temperature ranges (ambient and mean radiant)
- precipitation (amount and type)
- light (natural sunlight, shade, glare, artificial)
- humidity (amount, fog, mist, clouds)
- air circulation (wind, breezes).

When looking at various combinations of these factors, we can envision how people will sense the space, how they will interact with it and how they will experience it. This information enables us to utilize passive solar principles to design the landscape to maximize pleasurable experiences and minimize unpleasant experiences for people. Plants and built structures can be used to protect from temperature extremes, promote or redirect air currents and shade or reflect light.

The Index of Thermal Stress (ITS), developed by Givoni, explains the combined effect on the physiological and sensory response of the body, and is used to analyze the individual contributions of metabolic and environmental factors and predicts the physiological strain imposed on resting and working people. ITS takes into account temperature range, vapor pressure, air velocity, solar radiation, metabolic rate, and clothing. Below the comfort zone, the negative value of index indicates cold stress. (Givoni 1981) (Song 1987) Song studied the relationship between stationary and active outdoor behaviors to various climatic conditions. In Song's study, ITS had a stronger relationship with the frequency and duration of outdoor stationary behaviors than any single climatic factor in the fall, but in spring observations, the relationships were weaker. She concluded that during the fall, it was probable that people felt cold stress more, while they felt more comfortable in the spring. Song's study showed that increased solar radiation resulted in people staying longer on the plaza.



Figure 1.17 Wind Chill Chart

# New Wind Chill Chart

		Temperature (°F)																	
		40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
Wind (mph)	Calm	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
	5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
	10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
	15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
	20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
	25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
	30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
	35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
	40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
	45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
	50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
	55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98	

**Frostbite occurs in 15 minutes or less**

$$\text{Wind Chill (°F)} = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$$

Where, T = Air Temperature (°F)  
V = Wind Speed (mph)

(noaa news 2006)

## Wind

At times, the human body perceives the surrounding temperature, known as the sensible temperature, as warmer than it actually is. This is mostly apparent during cool, calm weather. This perception occurs because a thin layer of insulating air above our skin absorbs radiating body heat, becoming warmer

than the surrounding air.

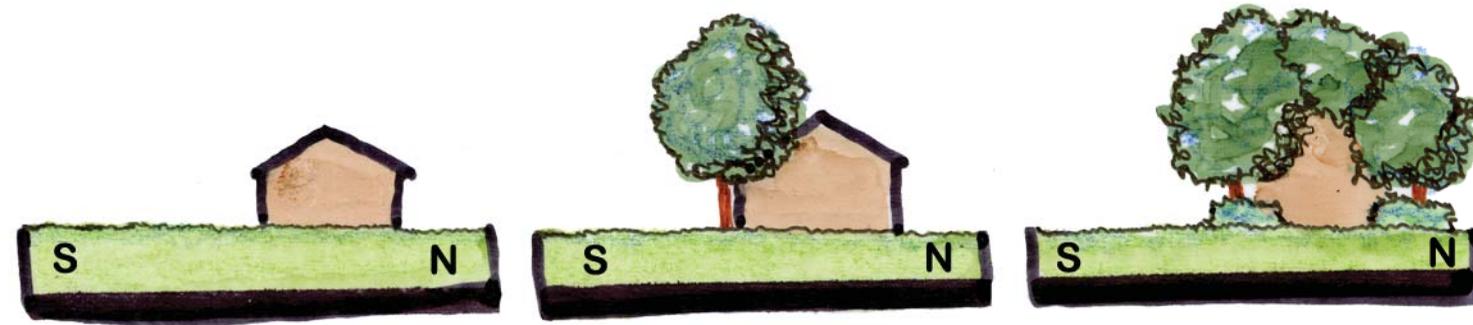
When the wind blows, this insulating layer is lost and we lose thermal energy to the air. How cold the air feels to the body is called wind chill. As the wind blows stronger, the sensible temperature drops. As the air temperature decreases, the wind

has a greater effect in reducing the sensible temperature. By mitigating windy conditions, the comfortable use of exterior spaces can be extended over a longer period of time. (Warner 1991)

Wind influences comfort through pressure effect, particle transport, and wind chill. Comfort is affected when wind pressure blows clothing and hair, lifts dust and grit particles to head level, and creates perceived or real resistance to walking. Wind velocity has a strong effect on whether people come to a site, how long they stay, and what they do while there. Calmer winds and pleasing breezes induce people to outdoor spaces for physical activities or just to rest. There is a weak trend for the average duration of stationary behavior to decrease as the wind velocity increases.

Modification of climatic conditions by landscape planning and design could increase outdoor behaviors and usage of outdoor space. (Song 1987) Whyte's observations found that the absence of winds and drafts was critical, and small parks enclosed on three sides functioned well, for users were physically and psychologically comfortable in them. Wind velocity near the living or ground level can be controlled to a certain extent by landscape planting. The frictional drag of vegetation, and the resistance and obstruction created by trees can cause diversions in the air flow which may be utilized beneficially. The value of tree wind breaks lies in their ability to reduce wind velocity. (Olgay 1963) (Song 1987)

# LANDSCAPING EFFECTS ON HOME TEMPERATURES



NO LANDSCAPING

TREE SHADING

TREES, SHRUBS & IVIES

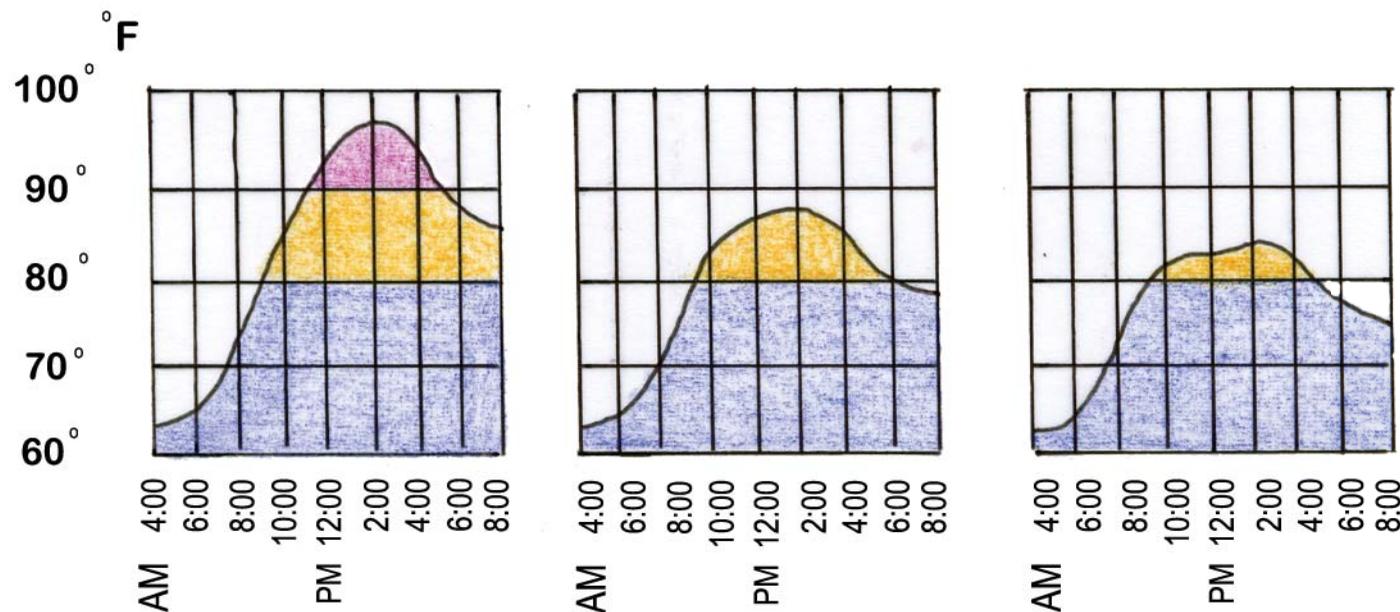


Figure 1.18 The dramatic effect of decreasing home temperatures is illustrated here. In this example, the interior temperature of the home is lowered by up to ten degrees by varying amounts and location of landscape trees and shrubs.

## PSLD Principles

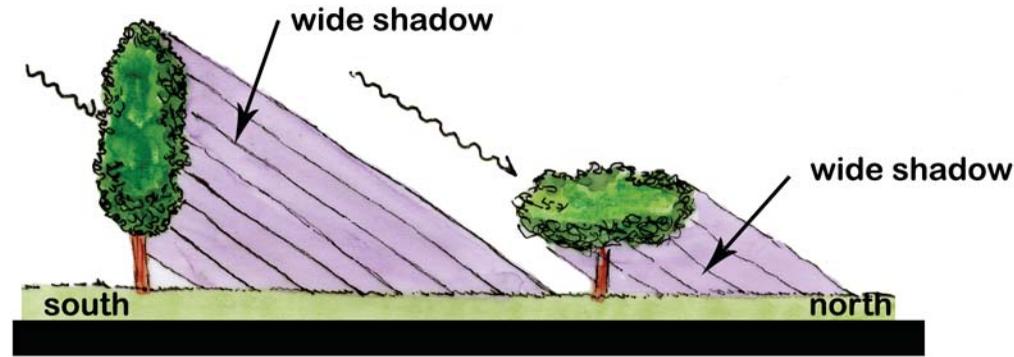
### Minimize heat absorption during summer

The temperature of densely built urban areas is often several degrees higher than surrounding rural areas due to increased storage of solar radiation and heat absorption, heat generated from automobiles, poorer radiant sky cooling and reduced wind speeds due to increased surface area and roughness. Planted sites within these urban areas can be ten to fifteen degrees cooler. This temperature difference is due to a combination of factors, including:

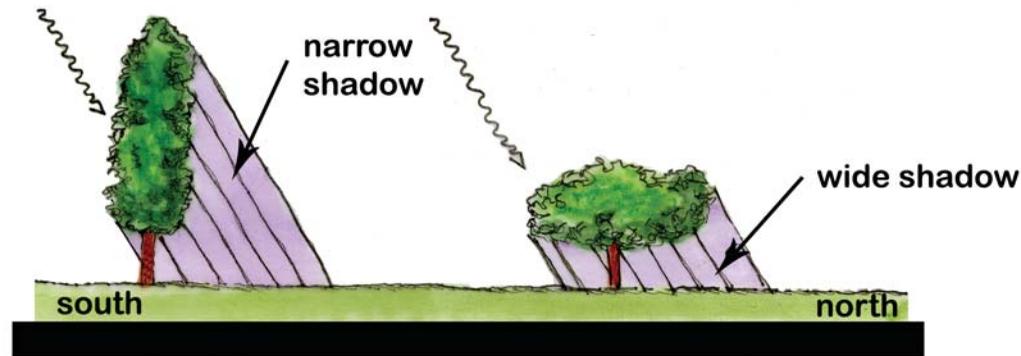
- evapotranspiration – loss of water from the soil by evaporation and transpiration from plants
- decreased heat holding capacity/greater cold storage capacity of plants
- increased moisture retention of soil
- increased reflection of solar radiation
- shade from trees and shrubs

There are two types of shade in the landscape: shade from structures and buildings, and shade from plant materials. Buildings can be shaded by trees and built structures. South and west facing windows should be shaded by roof overhangs, awnings or blinds. While shade patterns cast by buildings and structures will alleviate conditions of high solar insolation, they do not have the characteristic cooling effect of transpiring plants. This is due to the fact that plants release moisture through transpiration, which causes their shade to feel cooler thereby possibly alleviating greater levels of thermal discomfort. (Warner 1991)

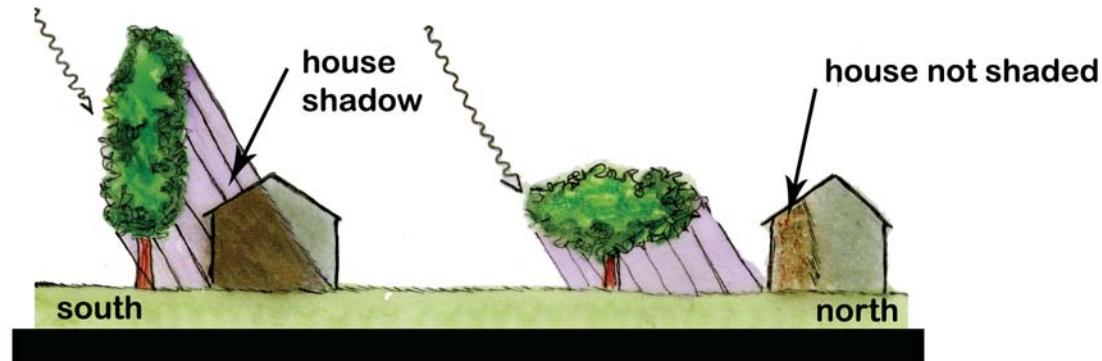
Low winter sun



High summer sun



High summer sun



Shading reduces external heat gain and is vital to passive cooling. According to the U.S. Department of Energy, combined mechanical and biological shading can reduce indoor temperatures by as much as 20°F. Trees and other vegetation not only provide shade to buildings and inhabitants, they also cool the surrounding air by evaporation. This process is known as transpiration, and draws enormous amounts of heat out of the air. (Chiras 2002)

Where parks are located in densely built areas, air circulation patterns form as the hot air rises up from the built areas and is replaced by the cooler air from the planted areas. (Brown 2001) In hot, arid climates evaporation is the primary means of cooling and in hot, humid climates shade has a larger proportional effect.

Deciduous trees are best for passive solar landscaping because they shade during summer and let solar radiation through in winter. When selecting trees for shade, growth rate, height, spread and shape must be considered. On the east and west sides of a house, the sun strikes from a low angle early and late in the day. To shade walls and windows on the east and west exposures, shrubs and smaller trees should be planted. Arbors and trellises work well here, and vines provide excellent shade.

Shade is a primary factor in designing outdoor spaces for human comfort. Different species of trees and shrubs provide varying degrees of shade. A thornless honeylocust casts dappled shade, while a white oak cast a deep shade. Built structures such as arbors, trellises and moveable shade structures such as patio umbrellas also provide varying degrees of shade.

## Sun Position and Shade

Figure 1.19 Landscape tree mature height, canopy spread and location must be considered when planning PSLD.

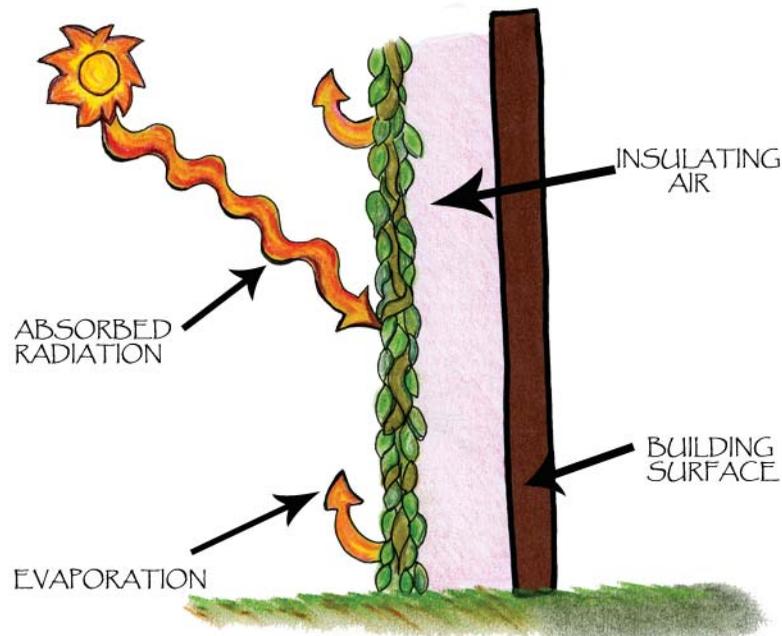


Figure 1.20 There is a layer of insulating air between this vine covered structure and the home, which warms the interior in the winter and cools it in the summer

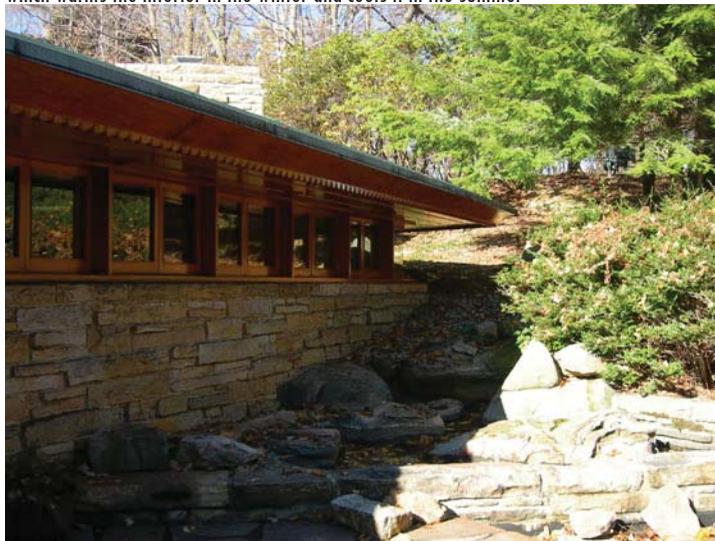


Figure 1.21 This home is built into a hillside which takes advantage of the warming and cooling effects of the earth

On the south side, it is best to plant high-crowned deciduous trees which grow tall and have few low-lying branches. Then, fully leafed-out in the summer, they shade the roof and south-facing wall, permit access to ground level breezes and permit sunlight to stream into south facing windows for passive solar gain in the winter. Trees and vines can lower the temperature of the air surrounding a home by as much as 9°F. Grass also helps cool the air around a house by as much as 10°F. Grass absorbs less sunlight and it loses moisture by transpiration-evaporation from the blades. Shade can also be achieved by planting evergreens, such as pines and spruces. They should not be planted on the south side, as they will block wintertime solar gain. They may block breezes that help passively cool a home.

Earth sheltering involves the partial to nearly complete burial of a house. This method of construction is known as earth berming. Earth sheltering allows us to benefit from thermal energy stored in the earth. Below the frost line, the ground stays a constant 50°F, plus or minus a few degrees. This is why most basements do not need mechanical cooling and minimal heat. Grottoes are good landscape examples of berming earth to create naturally cooled spaces. (Chiras 2002).

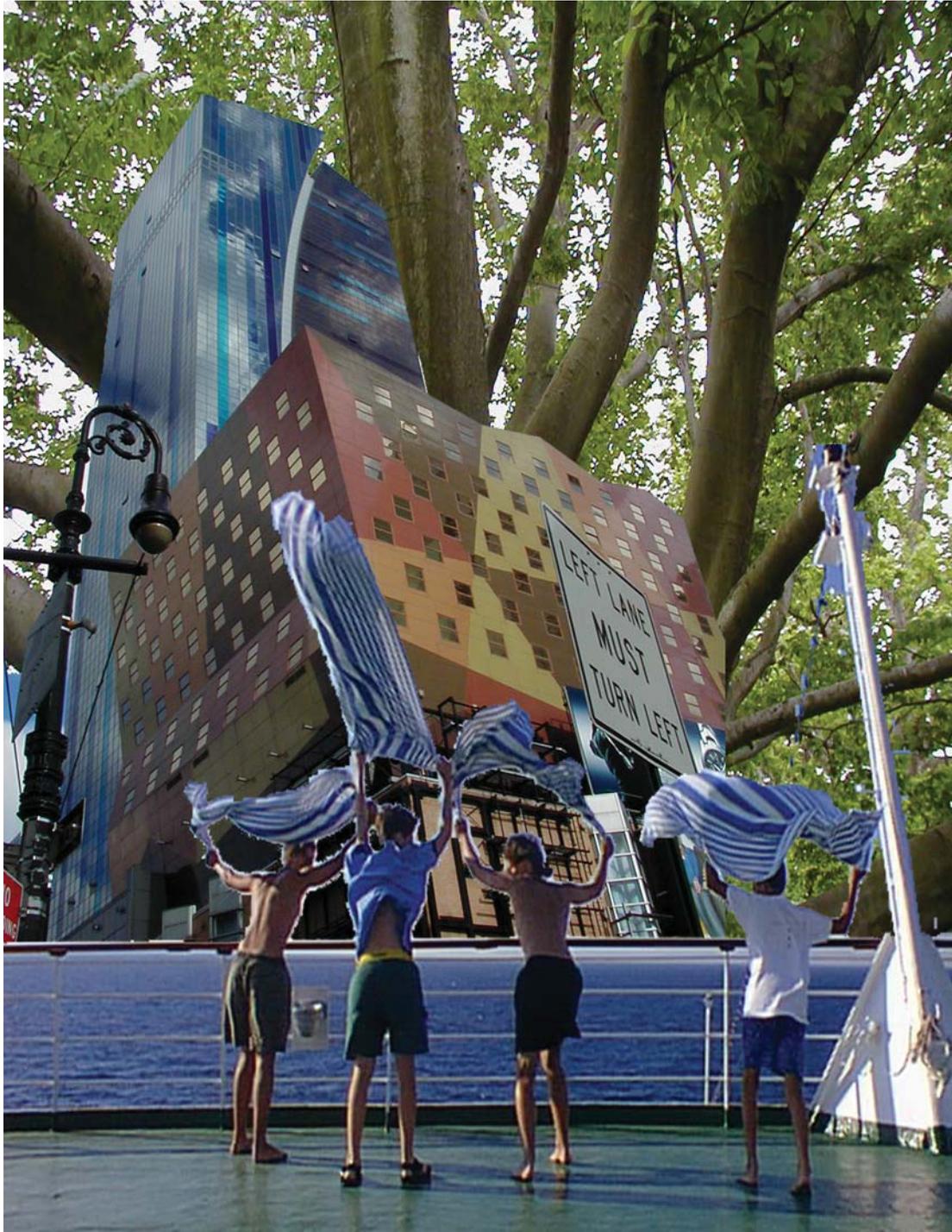
Windbreaks block cold winds that rob heat, while beautifying the area and provide food and shelter for native birds and animals. Wind load results from direct pressure, turbulence and suction. Wind resistance is least on plants and vines with a shallow profile. Plants that build up a considerable pillow of leaves and branching can catch the wind easily – enormous stresses. (Dunnnett 2004)

## Maximize heat absorption during winter

To use solar energy, we must utilize specific materials with high heat-absorption capacities to store heat for release later when direct radiation is no longer available. This occurs when heat absorbed from solar radiation is reradiated when

solar radiation is no longer available, and this requires a storage medium called ‘thermal mass’. The ‘thermal mass’ material is the limiting factor for effectiveness. Brick, stone and water make excellent thermal mass. Wood, wallboard and most metals are not good examples of thermal mass (Lyle 1994).

Thermal mass receiving direct sunlight is heated by radiation, which is the fastest means of heat transfer. The major vehicle for distributing heat within a building beyond a sunspace is convection. Roughly one-third of the solar radiation entering through transparent surfaces heats interior air. This heat is then distributed by convection to all spaces that are open to the heated area. Thermal mass located in all parts of the building in which air is warmed by convection can absorb heat for later release. Although the effectiveness of thermal mass heated by convection may be as little as one-quarter of that heated by radiation, its function is extremely important in keeping the whole interior warm (Lyle 1994). In the landscape, the same principles hold true. Thermal mass absorbs solar radiation and then reradiates it to warm the space. The increased comfort of hot seats, patios, courtyards and other outdoor spaces allows pedestrians to enjoy the garden during cold weather. In hot weather, landscape architects design the spaces to be shaded by trees and shrubs, creating an outdoor oasis.



## Maximize breezes during summer

PSLD uses the principles of air to its advantage in keeping a garden or building comfortable. Although many pedestrians find windy conditions unfavorable most of the time, breezes are always welcome in hot weather. Cooling breezes are especially important inside buildings. Principles of air include:

- Velocity
- Direction
- Pressure

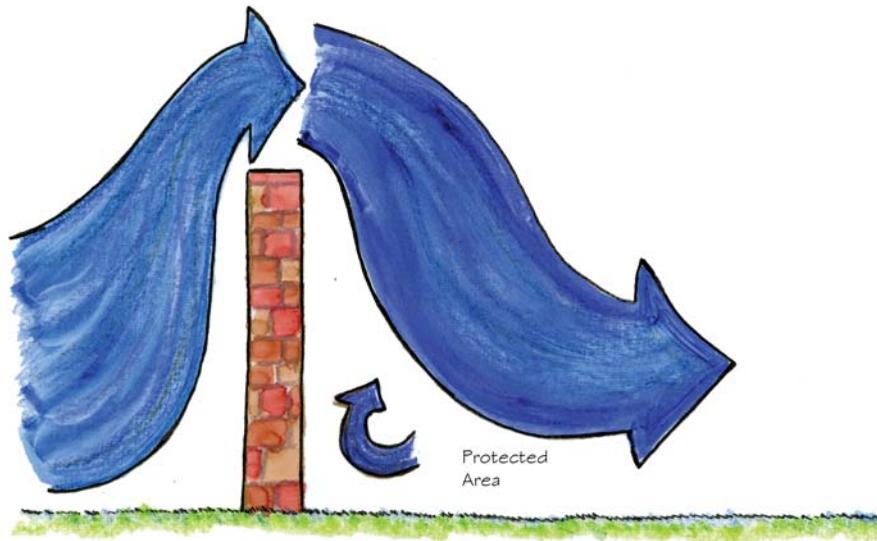
**Velocity** - As a result of friction, air velocity is slower near the surface of the earth and higher in the atmosphere. This reduction is a function of the ground's roughness. Different terrain types produce different velocities. Wind velocities measured at a site near the ground are frequently lower than those measured at the airport towers.

**Direction** - As a result of inertia, air tends to continue moving the same direction when it meets an obstruction. Air will flow around an object, like water around a rock in the river.

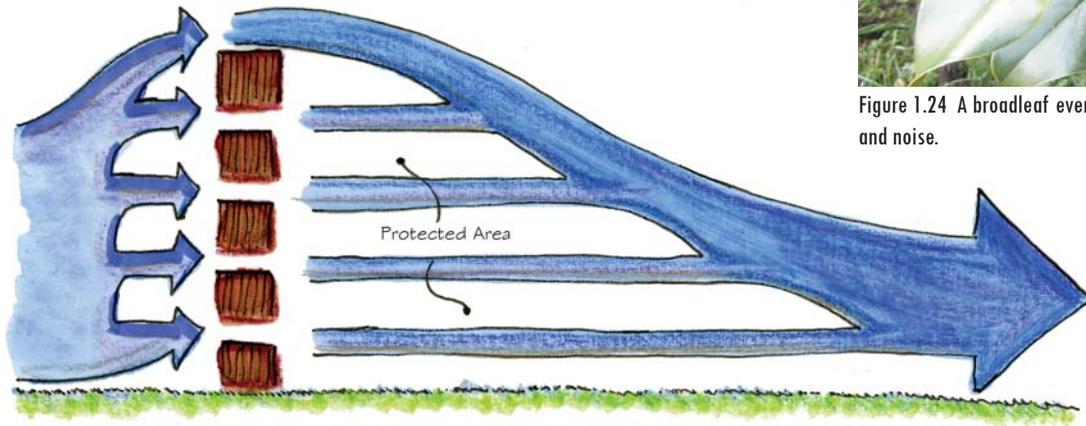
**Pressure** - Air flows from areas of high pressure to areas of low pressure. When solar radiation heats the air in a meadow, this reduces its pressure and the air rises. Air from the surrounding forest area will flow into the meadow area due to the vacuum formed by the rising air mass. This surrounding air is at a relatively lower temperature and at a higher pressure than the original air in the meadow. As in the second principle, air moves like water.

Wind scoops are elements added to roofs, and their purpose is catching the wind rather than the sun. The usual form is a plane which projects at an angle above a hollow shaft. The moving air bounces off the plane surface into the shaft, and travels down into the interior of the building. They are used often in India. (Lyle 1994)

Figure 1.22 The cooling effects of breezes coupled with landscape trees on buildings.



SOLID WINDBREAK



PENETRABLE WINDBREAK

Figure 1.23 The protected area on the leeward side of a solid barrier is much shorter than is a penetrable barrier, such as a fence, trellis or loosely-branched trees and shrubs.



Figure 1.24 A broadleaf evergreen such as this Magnolia, makes a good barrier to both wind and noise.

## Minimize cold wind blasts during winter

PSLD uses both plantings and hardscape to protect inhabitants and buildings from the harsh winter winds. Evergreen trees and shrubs are good choices, and broad leaf evergreens are a better choice than needled evergreens, due to their total surface area, which increases resistance to wind. Broad leaf evergreens' leaves are also angled in many directions, which deflect the wind well. Berms and raised planters increase the protective area by adding height and density. Built structures in the landscape, such as garden walls, fences and screens can help shield pedestrians and buildings from wind as well. A perforated windbreak has a much larger protected area than a solid one. This is true for trees and shrubs as well as built structures.

In PSLD, a windbreak of trees and shrubs planted perpendicular to the prevailing wind direction will have increased pressure on the side that the wind is blowing from (the windward side), and a protected area of decreased pressure on the downwind (leeward) side. A permeable windbreak allows some wind to pass through, resulting in a much larger area of protection than a solid windbreak because there is less pressure differential between the upwind and downwind sides. For example, a 25 foot tall evergreen windbreak provides the most effective protection at 125 feet away. Planting a densely branched evergreen screen can cut winds by 80%. Most deciduous trees in winter still carry 60% of their summer wind blocking capabilities. (Moffat et al. 1994)



Figure 1.25 Solar collectors power the Philip E. Merrill Environmental Center in Anapolis, Maryland

PSLD windbreaks can be designed and sited to lessen snow accumulation in unwanted areas. A solid windbreak, such as spruce or white pine will have deep drifts on both upwind and downwind sides, but they will not extend far. A permeable windbreak has no drift on the upwind side, but shallow drifts on the downwind side that extend farther, depending on the snow and wind velocity. PSLD windbreaks can be positioned to keep driveways, parking lots and walkways relatively free from snow accumulation compared to open areas. This occurs because the windbreak slows the wind down and the snow falls out of the air at that point.

## The Future

Incorporating solar power into your home or landscape will increase property value. According to the Real Goods, a green building company, the October 1999 *Appraisal Journal* reported that the average home value increases \$20 for every \$1 achieved in annual energy savings. Real Goods states that their 2.5kW average-size residential solar voltaic system can increase your property value by \$18,000 immediately, and it costs only \$16,000.

Schaeffer notes that in one 1999 report, a Photo voltaic system allowed you to lock in utility rates of \$.10 per kWh for 30 years. Electricity rates are expected to go up along with everything else, so more savings are in order (Schaeffer 2005). I feel that the current energy crisis and oil prices are a wake-up call for green building practices, including PSLD to be incorporated into as many new projects as possible, and to retrofit the principles into existing sites as maintenance and repair dictate.

# Case Studies

- The Farmer's Market in Old Town
- Kitchen Garden at Mount Vernon
- The National Zoo
- Finds and Conclusions



Figure 2.1 Stone insulates and provides a protective microclimate for this Forget-me-not

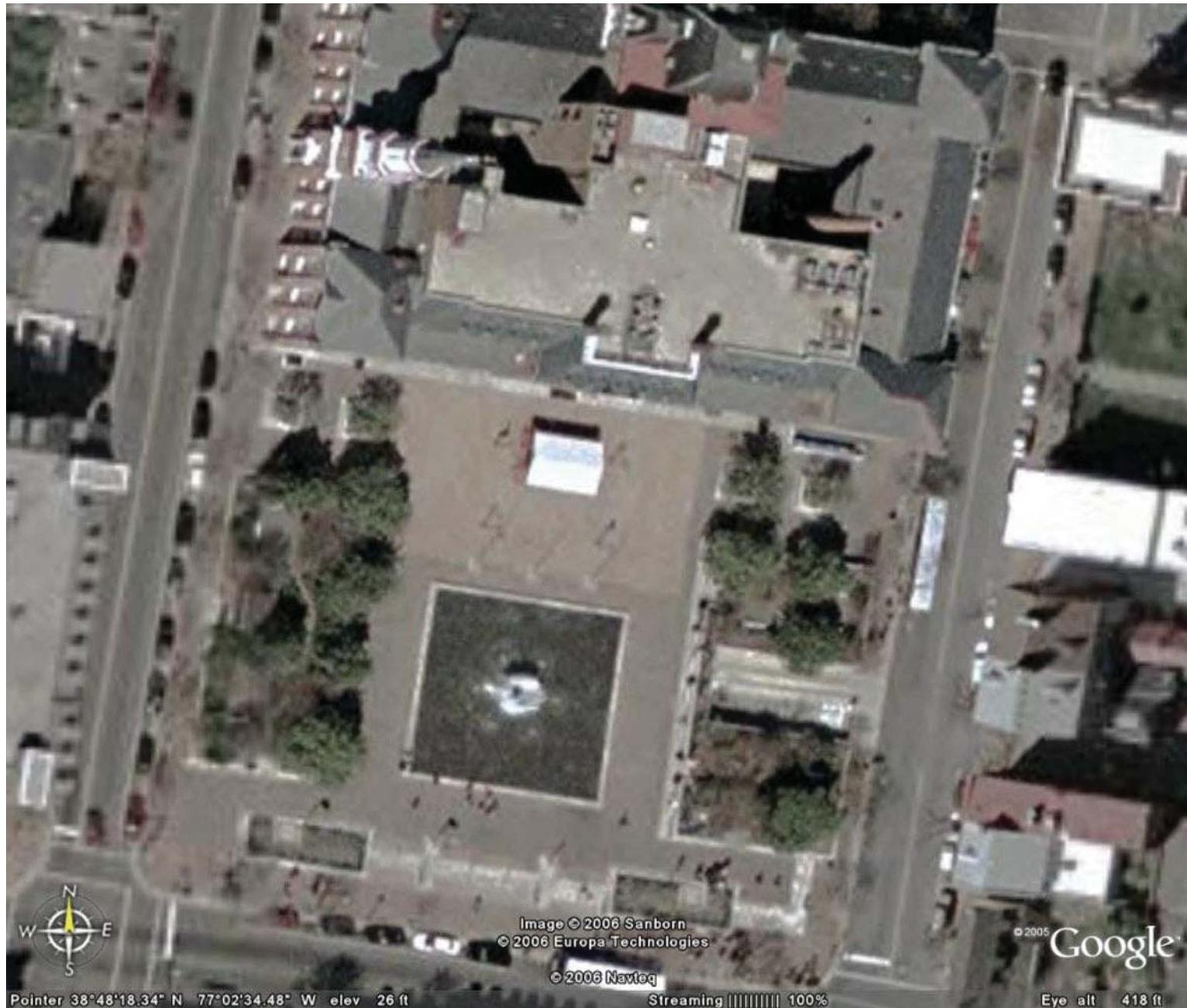


Figure 2.2 Google Earth image of Alexandria City Hall, site of the Alexandria Farmer's Market. Note the southern exposure and expanse of hardscape surrounding the central fountain.

## The Farmer's Market in Old Town

The farmer's market in Old Town, Alexandria is an example of PSLD principles used in an urban setting. The market is located at the City Hall plaza, and is open on Saturday morning's year around. The plaza is constructed of light grey granite and brick, with large raised planters on three sides and a large square central fountain. The raised planters provide seating and are planted with both deciduous and evergreen trees and shrubs. The plaza is open to the south, which allows solar radiation to warm the site in the winter. The walkways are paved with brick, and seating areas and steps are made of granite.



(A) People congregate in sunny areas during the cooler morning.



(B) Landscape plantings and hardscape combine to create comfortable microclimatic spaces in varied weather.



(C) Granite and brick absorb solar radiation and radiate it back into the site at night. Trees direct breezes and provide shade.



(D) The central fountain cools the immediate area and damps the noise of cars on King Street.

In hot weather, the light-colored granite absorbs less solar radiation than the darker brick, and is more comfortable to sit on. As heat rises from the brick to the level of the seat wall edges of the fountain, the water not only lowers the ambient temperature, the shooting fountain heads aerosolize water droplets, which cools the immediate area. The plantings provide shade along the sides and front of the plaza. Although the plantings partially block the ground level winds, the low pressure area created by the fountain combined with the width of the plaza and its open exposure allow in plenty of breeze.

In cold weather, the southern exposure of the plaza allows the thermal mass of brick and granite to absorb incoming solar radiation and radiate it back onto the site at night. The dormant crape myrtles allow more sunlight into the plaza. The magnolias help block winds from the east and west, and the brick courthouse building blocks them from the north.



Figure 2.4 Kitchen Garden cistern holds water for irrigation.



Figure 2.5 These Kitchen Garden fruit trees are espaliered along the surrounding brick wall where they will stay warm and protected from wind.



Figure 2.6 Google Earth image of George Washington's Mount Vernon in

## Kitchen Garden at Mount Vernon

The kitchen garden at Mount Vernon is another example of early PSDD principles at work. Sun, wind and water were all considered by George Washington when he designed Mount Vernon. The kitchen garden is located on the west lawn area, behind the stables, and its long axis lies east-west. The garden is terraced, which keeps it level and helps air circulation. A brick wall surrounding the kitchen garden serves several important purposes. The wall supports the garden terrace and keeps animals out of the garden. The wall is topped with a white picket fence along the north side, which extends the area of protection from harsh winds much farther than a solid fence



Figure 2.7 Google Earth image of the Kitchen Garden at Mount Vernon.



Figure 2.8 Sketch of the North wall of the Kitchen Garden

would. The brick absorbs solar radiation during daylight hours and reradiates the warmth into the garden at night.

The wall is tall enough to protect the plants from early spring frosts and winter winds, and its radiational heat helps melt snow and ice from the garden much sooner than the surrounding property. The kitchen garden's brick wall is approximately five feet tall at the top of the terrace and is level at the top, so that as the garden terraces down, the wall becomes taller, resulting in even greater warming of the soil and plants in the garden. A cistern in the central lower area holds water for irrigation.

Matt Petersmith, the head gardener of Mount Vernon, states that the fruit trees, ornamentals and vegetables everywhere in the kitchen garden except for the very center bloom and ripen much earlier than elsewhere on the property. Having produce at the center of the garden ripen later than those at the edges helps maintain a longer productive season. The growing season in the kitchen garden is also extended by more than one month because of the PSLD principles used. In George Washington's time, this could mean the difference between having food to last through the winter or not.

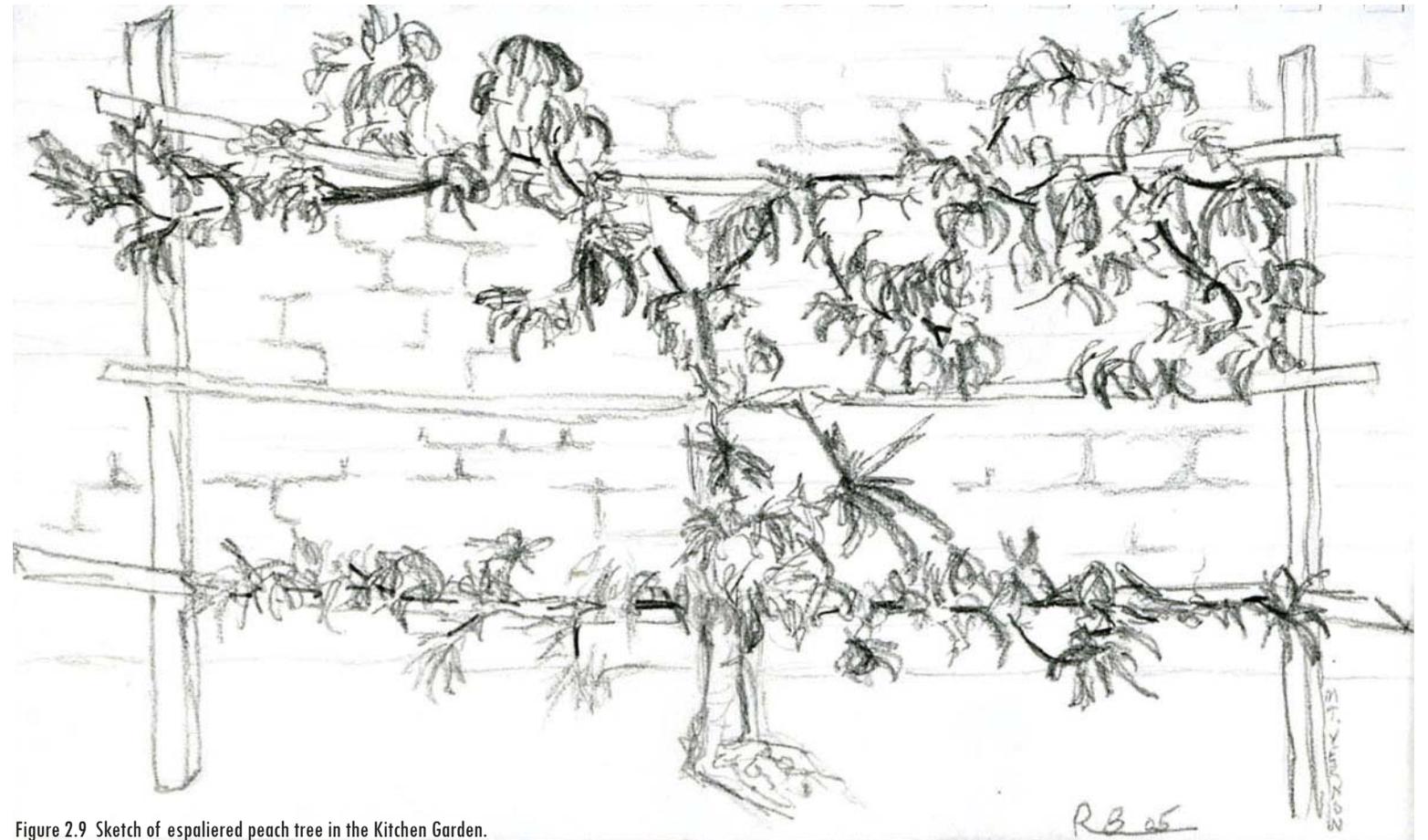


Figure 2.9 Sketch of espaliered peach tree in the Kitchen Garden.

# The National Zoo

The National Zoo in Washington, D.C. uses a variety of means to keep both animals and visitors comfortable through PSLD including:

## Solar:

- Animal enclosures constructed of concrete and stone – absorbs/reflects solar radiation as needed to simulate natural environments. Color and type of surface coating reflect or absorb solar energy. ‘Hot rocks’ and ‘Cold rocks’ have heating or cooling mechanisms embedded in them which can be mechanically or automatically operated. Produces comfort and stimulation to interact with environment
- Shade is provided throughout the year by use of deciduous and evergreen trees, shrubs, hardscape and man-made structures
- Pedestrian paths and lookouts are both shaded and open to solar energy in different areas by evergreen and deciduous plantings, and surfaced by concrete or asphalt. Pedestrian lookouts are usually open and not shaded.

## Wind:

- Cold environments are open to the prevailing winter winds
- Hot environments are protected from the prevailing winter winds
- Protection provided through careful placement of hardscape, man-made structures and deciduous and evergreen plantings.



Figure 2.10 Watercolor sketch of a tiger basking on a terraced hillside at the National Zoo. The concrete retaining wall is fronted by various tall plants and the area is well shaded by large trees.

## Water:

- Used in many exhibits for temperature control, simulation of natural environments and stimulation for animals
- Pools and misting systems cool the areas for both animals and pedestrians
- Water temperature is controlled by thermostat in many enclosures.
- Absorbs solar radiation and reflects heat back into hot climate animal enclosures.





Figure 2.12 Illustration of how hardscape can provide a warm seating area for viewing animals in cold weather, and be cool and shaded by the tree canopy in warm weather. These properties also have the same effect on the animal enclosure behind the glass, creating comfort for the animals.

Plantings at the National Zoo are very important as food, shelter and protection. Shade is essential for the animal's comfort, health and simulation of their natural habitat. Pruning is important, as it stimulates growth, controls growth patterns, helps contain animals and promotes visual avenues for the public to view the animals. Pruning lower branches at sharp angles can deter the animals from climbing in areas where it could result in injury or escape.

My visits to the National Zoo have all been in hot weather, and I feel that both the animals and visitors' comfort have been taken into consideration during the design and construction. Although some overlooks are very hot due to the combination of asphalt and sunlight, there are often breezes and shade from surrounding trees in the morning and late afternoon. The animals housed in air conditioned buildings, such as the Bird House, Ape House and the Reptile House provide welcome respite from the heat.

# Relationship Between Areas Of Fossil Fuel Use and Passive Solar Effects At Case Study Sites

Site	Fossil Fuel Use	Passive Solar	Relationship between fossil fuel use and passive solar uses
Farmer's Market – City Hall, Alexandria, VA	<ul style="list-style-type: none"> <li>• Electricity</li> <li>• Water fountain</li> <li>• Granite/hardscape</li> <li>• Lighting</li> </ul>	<ul style="list-style-type: none"> <li>• Plantings – direct winds and provide shade</li> <li>• Granite/hardscape</li> <li>• Fountain</li> <li>• Orientation – southern exposure</li> </ul>	<ul style="list-style-type: none"> <li>• Plantings provide shade</li> <li>• Hardscape absorbs/radiates heat</li> <li>• Water fountain cools immediate area</li> <li>• Siting – solar warming</li> </ul>
Mount Vernon Kitchen Garden, Mount Vernon, VA	<ul style="list-style-type: none"> <li>• Maintenance</li> <li>• Equipment</li> </ul>	<ul style="list-style-type: none"> <li>• Walls/hardscape</li> <li>• Orientation</li> <li>• Limited plant pallet</li> </ul>	<ul style="list-style-type: none"> <li>• Brick walls extend growing season by radiating solar energy</li> <li>• Walls block wind</li> <li>• Local materials and fertilizer</li> </ul>
Smithsonian National Zoological Park Washington, DC	<ul style="list-style-type: none"> <li>• Heating and cooling habitats</li> <li>• Electricity</li> <li>• Paving</li> <li>• Maintenance</li> <li>• Equipment</li> <li>• Transportation</li> <li>• Food services</li> <li>• Sanitation, water treatment</li> <li>• Lighting</li> <li>• Acquiring feed/supplies</li> </ul>	<ul style="list-style-type: none"> <li>• Plantings channel/block winds</li> <li>• Walls</li> <li>• Berms/earth forms</li> <li>• Buildings</li> <li>• Orientation varies</li> <li>• Use of water</li> </ul>	<ul style="list-style-type: none"> <li>• Walls, boulders and vertical hardscape block or direct winds for comfort</li> <li>• Hardscapes absorb or reflect solar energy</li> <li>• Earth forms used for shelter and play/digging</li> <li>• Plantings used for shade, food, habitat</li> </ul>



Figure 2.13 Matrix of the relationship between areas of fossil fuel consumption and areas of passive solar use in my case study sites.

## How Passive Solar Principles Are Implemented At Case Study Sites

Site	Earth	Fire	Wind	Water	Hardscape
Farmer's Market – City Hall, Alexandria, VA	<ul style="list-style-type: none"> <li>Trees and plants slow down evaporation</li> <li>Granite warms and cools visitors</li> </ul>	<ul style="list-style-type: none"> <li>Granite absorbs and radiates solar energy</li> <li>Water absorbs, reflects, radiates solar energy</li> </ul>	<ul style="list-style-type: none"> <li>Trees block/direct winds to create microclimates</li> <li>Wind currents around City Hall building</li> </ul>	<ul style="list-style-type: none"> <li>Central fountain cools immediate area</li> <li>Play area for visitors</li> <li>Radiates solar energy</li> </ul>	<ul style="list-style-type: none"> <li>Granite and brick</li> </ul>
Mount Vernon Kitchen Garden, Mount Vernon, VA	<ul style="list-style-type: none"> <li>Garden fertilized by stables</li> <li>On-site plant propagation and sales of seeds</li> </ul>	<ul style="list-style-type: none"> <li>Garden wall raises temperature – extends growing season</li> <li>Southern orientation</li> </ul>	<ul style="list-style-type: none"> <li>Winds blocked or directed to protect plants</li> <li>Breezes pollinate plants</li> </ul>	<ul style="list-style-type: none"> <li>On site cistern for irrigation</li> </ul>	<ul style="list-style-type: none"> <li>Brick and wood</li> </ul>
Smithsonian National Zoological Park Washington, DC	<ul style="list-style-type: none"> <li>Used extensively for habitat, food, shelter</li> <li>Microclimates for humans as well as animals</li> </ul>	<ul style="list-style-type: none"> <li>Stone asphalt absorbs and radiates solar energy</li> <li>Orientation of pens and buildings</li> <li>Overhangs shade and warm.</li> </ul>	<ul style="list-style-type: none"> <li>Hardscape and plantings allow or block winds, depending on needs of animals</li> </ul>	<ul style="list-style-type: none"> <li>Used extensively for pools and cooling animals</li> <li>Recirculating – not continuous fresh water supply</li> </ul>	<ul style="list-style-type: none"> <li>Stone, paving, wood</li> </ul>

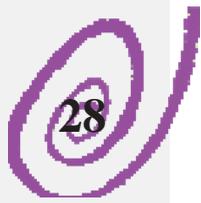


Figure 2.14 Illustration of how passive solar principles are implemented in my case study sites.



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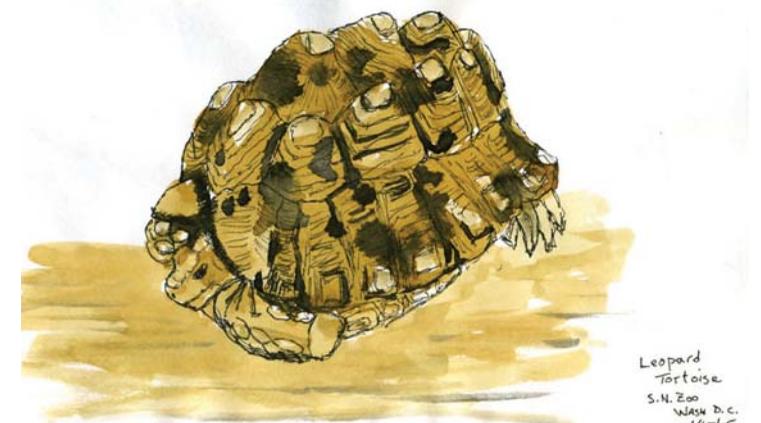
## Findings

The King Street farmer's market, the Mount Vernon kitchen garden and the National Zoo all exhibit varying degrees of PSD. The King Street farmer's market site is the most uncomfortable environment of the three due to the expanse of brick and granite, and poorly located trees planted in perimeter locations. While cooler in the shade of the trees in hot weather, the rest of the plaza is unprotected and hot - even the granite surrounding the fountain gets too hot to sit on comfortably. The main problem from a PSD viewpoint is that the trees are on the east and west sides of the plaza and the southern sun beats down on you mercilessly. Any cooling breeze coming off the Potomac River to the east is blocked or diverted by the trees. The lack of plant life on the north or south sides of the plaza make it seem like a wind tunnel during the winter. During the spring and fall, the plaza is quite nice, although the granite can be cold to sit upon on overcast days.

The Mount Vernon kitchen garden conforms well to PSD principles. It's east-west long axis assures that all plants receive adequate sunlight and shading by other plants is kept at a minimum. The picket fence atop the brick wall directs cold northern winds upward and over the garden, but allows some wind through, thereby greatly increasing the area protected from the wind and cold. The brick wall surrounding the garden absorbs solar radiation and radiates the heat back into the garden at night. Terracing helps with water conservation, and the on-site cistern makes irrigation more efficient.

Figure 2.15 Plantings provide food, shelter and temperature control for giraffes and other animals at the National Zoo.

The National Zoo exhibits the most complete example of PSD principles. I think that it is due to a combination of the number of people who are involved in planning the exhibits, consideration of environmental conditions being at the forefront of decision making, and being a modern landscape with current technology and research at hand. Both plant life and hardscape are used to make habitats which closely resemble native habitats for the animals. Trees provide shade, wind protection and allow the winter sun to warm the enclosures and visitors alike. Hardscape walls, fences and buildings protect from the hot sun, rain and strong or cold winds and radiate heat into the enclosures for night comfort. Water is used as pools or streams in many enclosures, and the animals take advantage of its cooling properties. The water also cools the immediate area so that the visitors feel relief from the heat.



Leopard  
Tortoise  
S.N. Zoo  
WASH D.C.  
6/15/15

Figure 2.16 Hardscape provides a clean, easily maintained and heated environment for reptiles like this Leopard Tortoise in the Reptile House at the zoo.

## Research Conclusions

Man has always used earth, fire, wind and water to make his existence more comfortable. How a site is used is of prime importance in utilizing the benefits of PSLD. People use sites more on sunny days with little wind. Wind velocity is considered a cooling mechanism during climate profiles of high temperature and high humidity. While cooling breezes are important, the wind also plays a significant negative role as wind chill in cooler seasons. Wind chill will add more days to the uncomfortable zone, if not considered. Similar results occur above the comfort zone in warmer weather conditions, due to increased solar radiation levels and high ambient temperatures combined with high humidity levels which produce higher levels of thermal discomfort. This must be compensated for by providing shade, wind or water to the site.

This study stated that Givoni and Olgyay observed that shade does not become an important factor influencing behavior until temperatures approach 85°F. At this temperature level, the majority of plaza users will orient themselves in shaded areas. This information can be important to designers of outdoor spaces aiding decisions for orientation of shade patterns based on the time of day or the time of year.

During warmer seasons, shading may not be necessary during the early hours of the day before temperature and solar radiation levels reach their daily peaks. By mid-day however, these levels may dictate shading to insure thermal comfort of occupants. The orientation of the sun angle at mid-day can indicate installation locations for shading structures or plants to reduce thermal stress. (Warner 1991)

**Minimizing heat absorption and maximizing**

breezes in hot weather and maximizing heat absorption and minimizing wind blasts during cold weather for comfortable occupation are the main goals of PSLD. A reduction in our fossil fuel consumption will result from utilization of PSLD principles. The case studies of the Farmer's Market, the Kitchen Garden at Mount Vernon, and the National Zoo grounds are examples of how PSLD principles work, allowing us to harvest the benefits of solar, wind and water power.

Passive solar design focuses on using both plants and built structures to create microclimates which make a site more comfortable for humans to inhabit and lower the amount of heating and air conditioning required to maintain human comfort levels inside buildings. People will occupy their landscapes for longer periods of time and more often if they are comfortable. Travel to other locations in search of comfort will be decreased.

Implementing PSLD principles can be incorporated into existing landscapes or designed from the site analysis of a piece of land, regardless of location. Existing landscapes should be thoroughly analyzed to create strategic microclimates which will have the greatest impact on human comfort and greatest reduction of heating and cooling costs of the dwelling.

Reducing heating and cooling costs and spending less time traveling will make a dramatic impact on our fossil fuel consumption. Both can be easily achieved by implementing PSLD into our society.

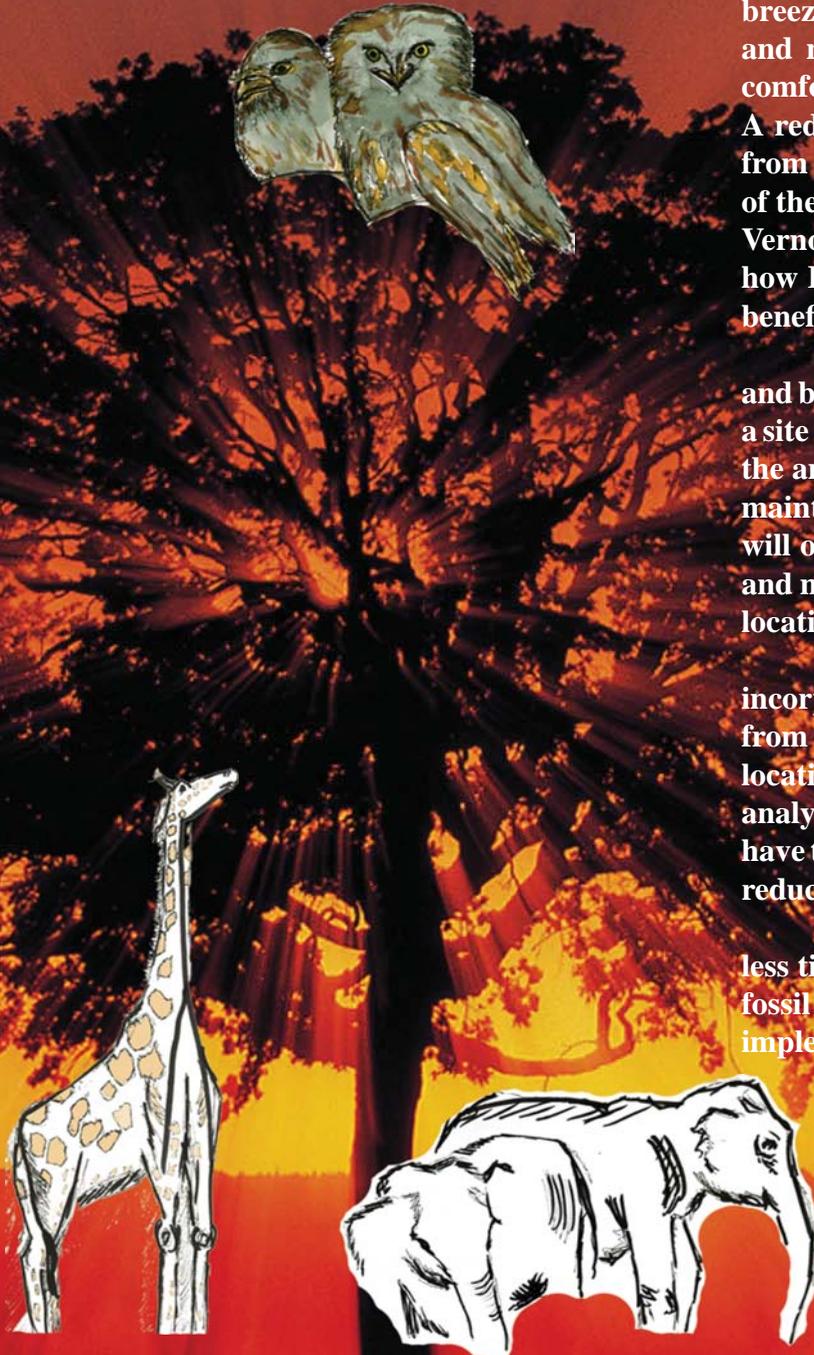


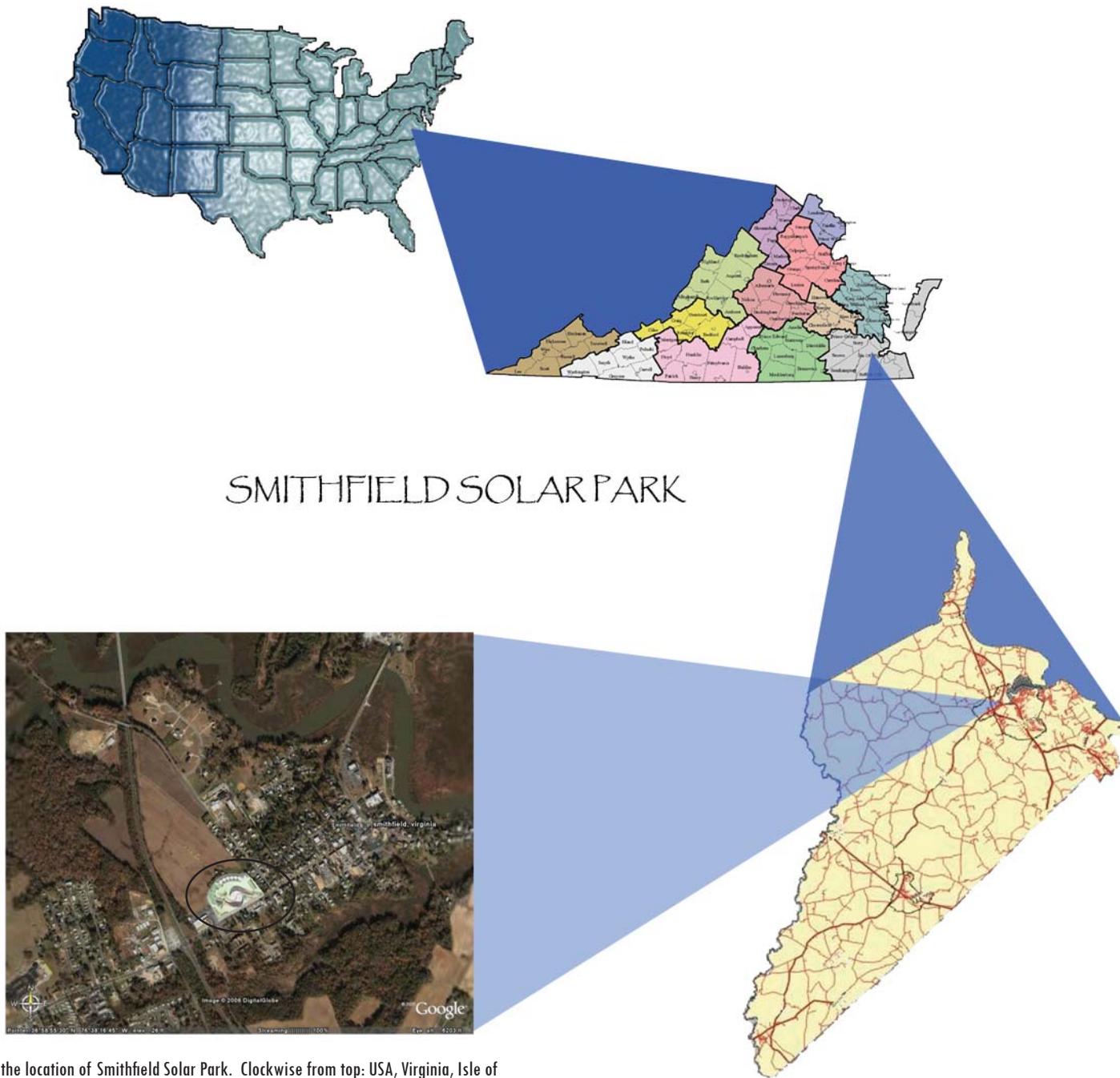
Figure 2.17 Illustration of how the earth, landscape plantings and the sun work in harmony in PSLD to create microclimates of thermal comfort, shelter and habitat for humans and animals alike.

## Part II: Investigation

- **Site Analysis**
- **Weather**
- **Site Photography**



Figure 3.1 Earth, wind, fire and water - the principle components of PSLD, work together and are interrelated as the roots of this magnificent shade tree at Dumbarton Oaks. The canopy and the grass cool the area during hot weather and allow solar radiation in to warm it during cold weather, extending outdoor enjoyment.



### The Site

Smithfield, Virginia is located on the Pagan River directly across the James River from Jamestown. Smithfield, in Isle of Wight County, was colonized in 1634. Smithfield was named after Arthur Smith IV, and was incorporated in 1752. Smithfield was a river town from its beginning, and still has its historical charm.

Figure 3.2 Diagram showing the location of Smithfield Solar Park. Clockwise from top: USA, Virginia, Isle of Wight County and Smithfield Solar Park sited in the historic district of Smithfield.



Figure 3.3 Google Earth image of the Town of Smithfield, Virginia. The site of Smithfield Solar Park is highlighted in red. The major entrances into the historic district are highlighted in blue. The eastern and western ends of Main Street are the main points of entry into the historic district, and are highlighted in light blue.



Figure 3.4 Author's vision of crowds of visitors shopping on Main Street while attending one of the many local and regional activities at Smithfield Solar Park.

Smithfield is the home of many activities from April through December, and all are well attended by locals as well as people from the surrounding area. Having lived in Smithfield for several years, I noticed that although there were many activities, they were either not on an appropriate place to host the activity, or it was too small. I had already decided on designing a solar park, and the thought of siting it in Smithfield was exciting from the beginning.

I decided to site my park on the western end of Main Street, adjacent to Little's Supermarket. This end of Main Street is almost forgotten, being right on the edge of the Historic District and just yards away from the true 'commercial area' of town. I wanted my park to tie the western end of Main Street back into the lively and bustling Historic District and bring the commercial district farther down to the Route 10/Route 258 intersection. I also wanted to design a park that could host regional events as well as weekly local ones.

Smithfield needs a public park that will give people a sense of community and will be a self-sustaining part of the Historic District. This park needs to be able to increase visitation to the area through varied events for all ages, and this will increase revenue for the town. This inspired me to design a multi-use solar park that not only educates the public about PSLD, but encourages year around community activities.

My project goals are to design a solar park featuring:

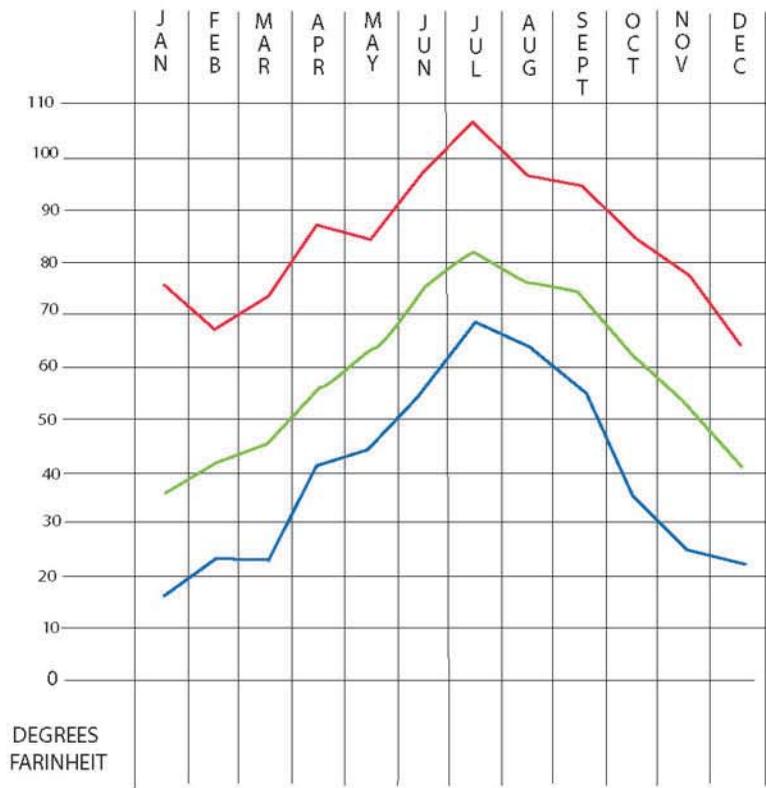
- a solar powered educational/meeting center
- a solar powered farmer's market pavilion
- outdoor movie amphitheater
- space for concerts, festivals and holiday celebrations

The passive solar landscape park goals are:

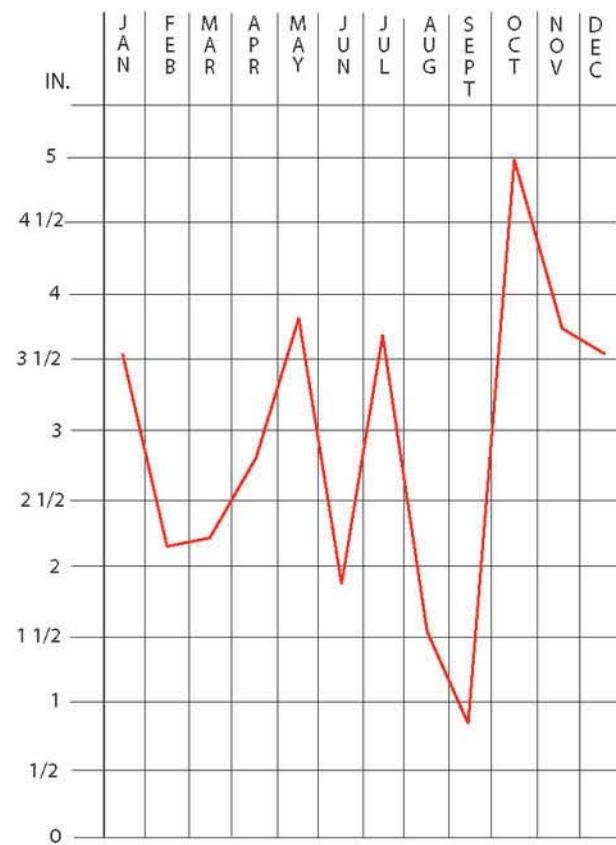
- make it cool in the summer
- make it warm in winter
- make it self-sufficient
- educate the public about psld
- create a sense of community

# 2005 WEATHER PATTERNS FOR SMITHFIELD, VIRGINIA

## TEMPERATURE



## RAINFALL



## PREVAILING WIND DIRECTIONS



The soil in Smithfield is sandy and has good drainage. Weather conditions are moderate and typical for Virginia. Seasonal wind direction is a very important part of PSLD.



Figure 3.5 The 2005 Temperature, Rainfall and Monthly Prevailing Wind Direction weather information collected for Smithfield, Virginia. This information was used extensively during the design of Smithfield Solar Park. Weather information gathered from internet and designed into charts by author. (Weather Underground 2006).



Figure 3.6 Panoramic photograph of Main Street across the street from Smithfield Solar Park site. The park is located at the eastern edge of Little's Grocery Store parking lot (at the far right) which can provide overflow parking.



Figure 3.7 Panoramic photograph looking west on Main Street. The field bordered in black is the front of the Smithfield Solar Park site.



Figure 3.8 Panoramic photograph of businesses and a car wash on Main Street, just east from the Smithfield Solar Park site. Notice the run-down appearance of the car wash in comparison to the other businesses.



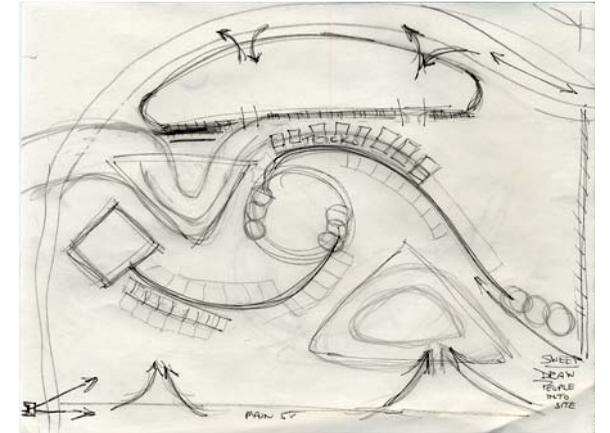
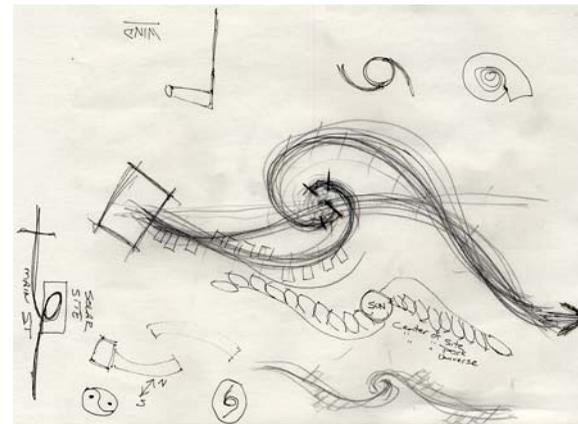
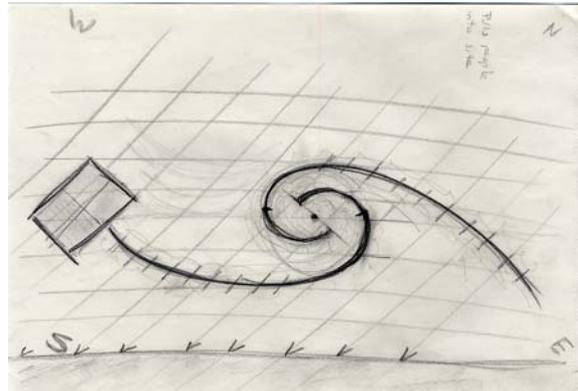
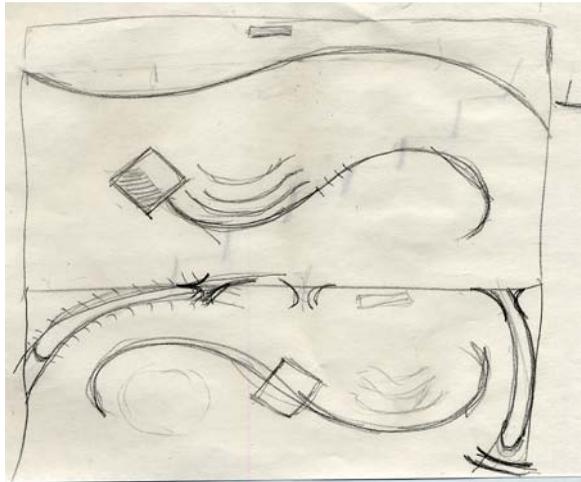
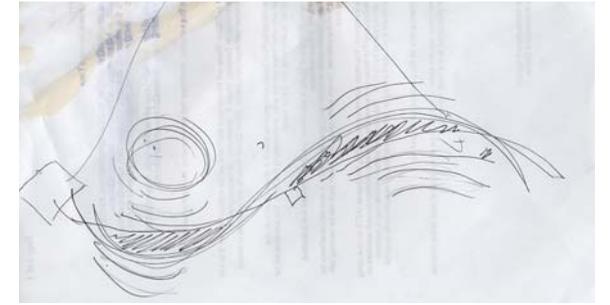
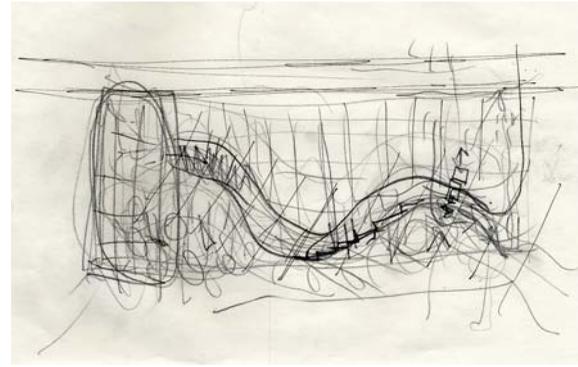
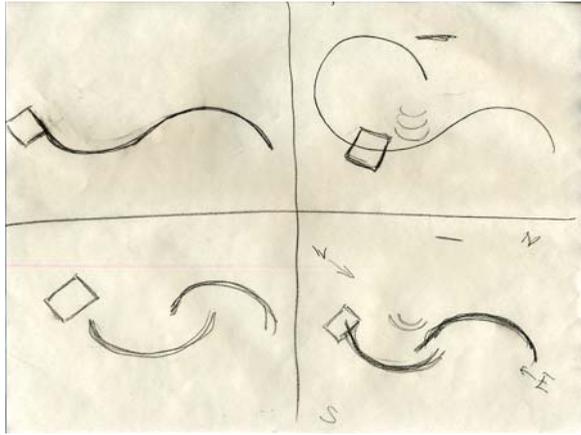
Figure 3.9 Photograph of the eastern edge of Little's parking lot and the western edge (bordered in black) of Smithfield Solar Park's demonstration garden and Solar Educational Center.

# The Design

- Progression sketches
- Initial master plan
- Revised master plan
- Park renderings
- Park model



Figure 4.1 Author's watercolor, graphite and ink drawing of oyster shell, and sketches.



### Design Progression Sketches

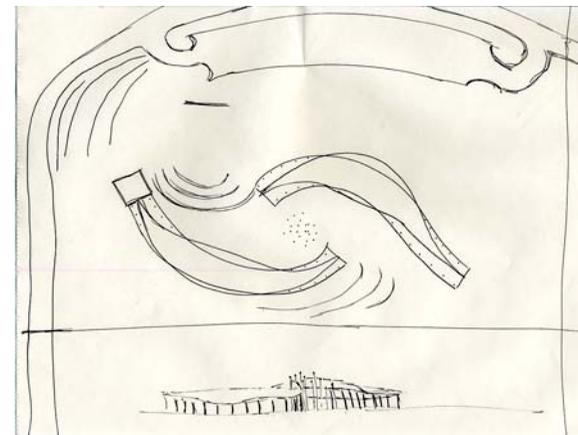
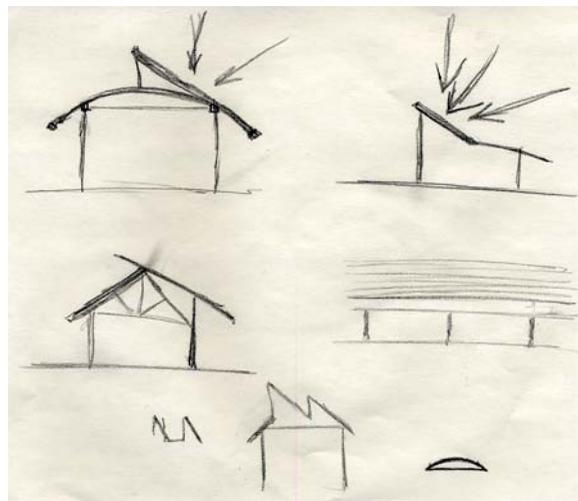
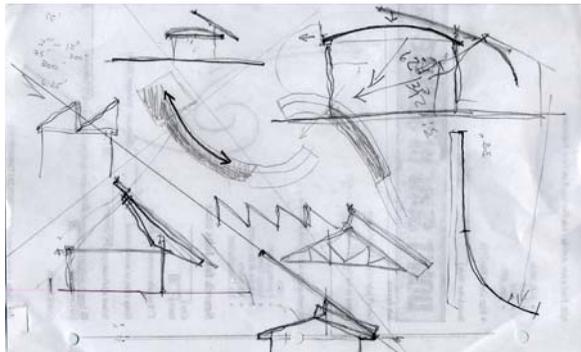
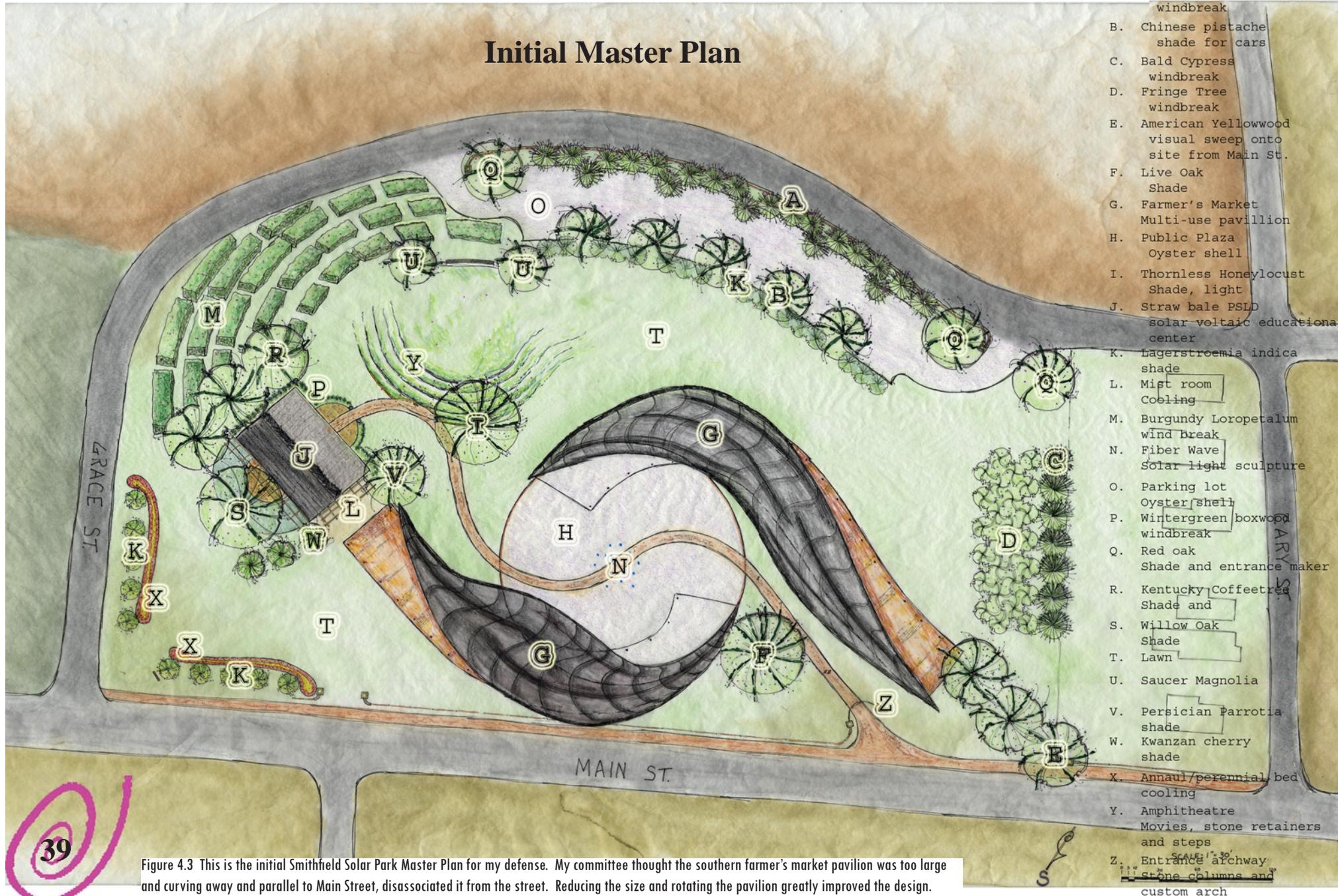


Figure 4.2 The progression of the site beginning with the enlightenment from Paul Emmons that my little square farmer's market did not have to be square. The mere suggestion that a farmer's market could be linear was all I needed to develop the final design.

## Initial Master Plan



### LEGEND

- A. Yoshino Cryptomeria windbreak
- B. Chinese pistache shade for cars
- C. Bald Cypress windbreak
- D. Fringe Tree windbreak
- E. American Yellowwood visual sweep onto site from Main St.
- F. Live Oak Shade
- G. Farmer's Market Multi-use pavillion
- H. Public Plaza Oyster shell
- I. Thornless Honeylocust Shade, light
- J. Straw bale PSD solar voltaic educational center
- K. Lagerstroemia indica shade
- L. Mist room Cobling
- M. Burgundy Loropetalum wind Break
- N. Fiber Wave Solar light sculpture
- O. Parking lot Oyster shell
- P. Wintergreen boxwood windbreak
- Q. Red oak Shade and entrance maker
- R. Kentucky Coffeetree Shade and
- S. Willow Oak Shade
- T. Lawn
- U. Saucer Magnolia
- V. Persicaria Parrotia shade
- W. Kwanzan cherry shade
- X. Annual/perennial bed cooling
- Y. Amphitheatre Movies, stone retainers and steps
- Z. Entrance archway Stone columns and custom arch

### Strengths:

- PSD principles well thought out and implemented.
- Varied planting plan which has plants blooming at various times of the year and also interesting bark, leaves, canopy shape, etc.
- Proximity to historic district
- Well thought out reasoning for site selection.
- Adequate space for the planned community events and activities.

### Weaknesses:

- Lack of walkways throughout the park.
- Southern pavilion too large and awkwardly oriented to Main Street.
- Southern pavilion too close to Main Street.
- No clear line of sight or pathway to the amphitheater.
- No walkway from the parking lot to the pavilions.
- Basic pedestrian circulation is lacking.

Figure 4.3 This is the initial Smithfield Solar Park Master Plan for my defense. My committee thought the southern farmer's market pavilion was too large and curving away and parallel to Main Street, disassociated it from the street. Reducing the size and rotating the pavilion greatly improved the design.

# SMITHFIELD SOLAR PARK EDUCATIONAL CENTER AND AMPITHEATRE

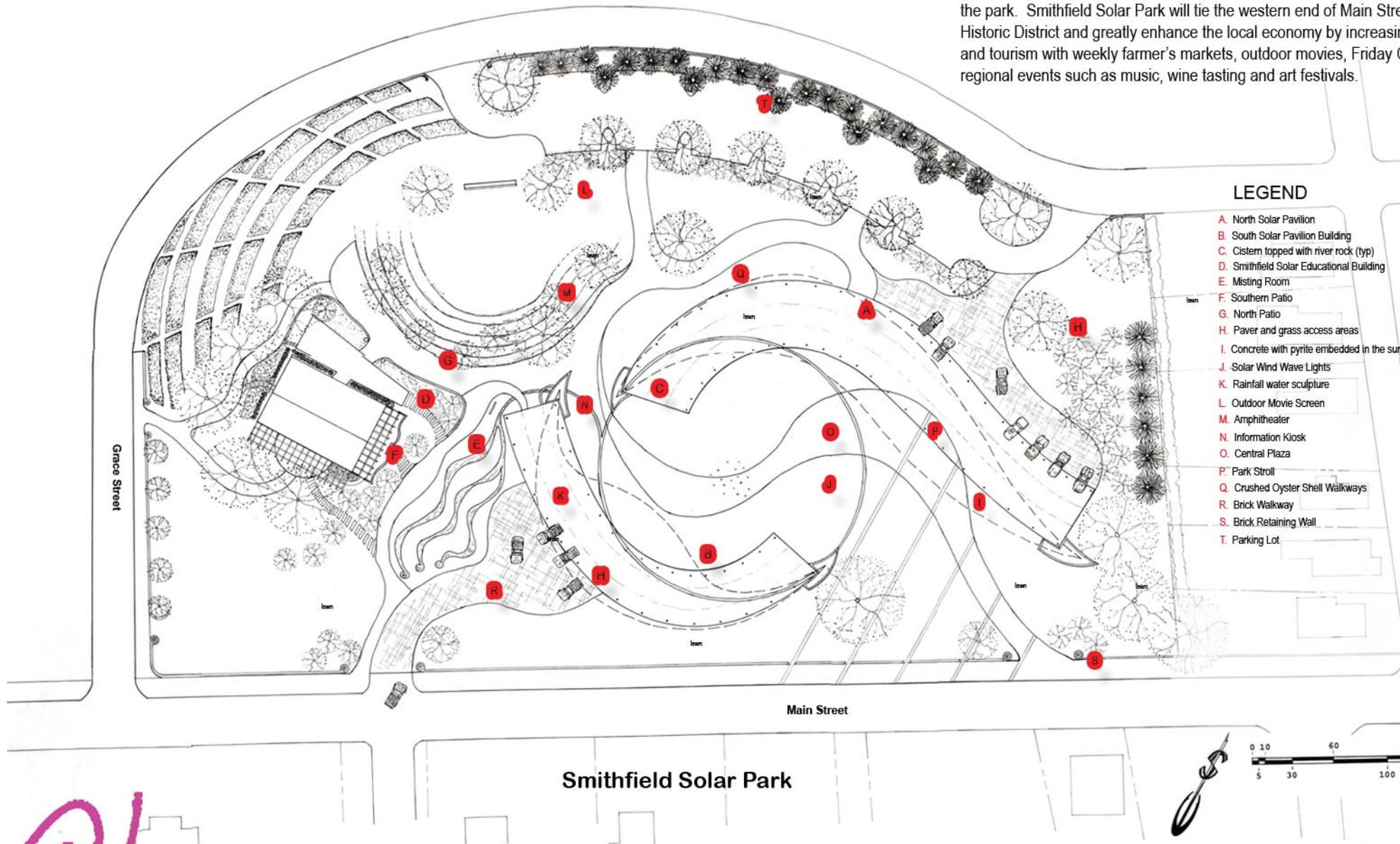
CREATING MICROCLIMATES THROUGH PASSIVE SOLAR LANDSCAPE DESIGN



Solar Park - Monthly Prevailing Wind Directions

Figure 4.4 The 2005 monthly prevailing wind directions for Smithfield, VA are depicted by corresponding color. The arrow shaft shows the direction from which the wind is blowing and points in the direction in which it is blowing. <http://www.wunderground.com/US/VA/Smithfield.html>. January 13, 2006.

Smithfield Solar Park is located at the edge of historic Smithfield, Virginia. The circular shape of the farmer's market pavilions draws visitors into the park. Smithfield Solar Park will tie the western end of Main Street to the Historic District and greatly enhance the local economy by increasing visitation and tourism with weekly farmer's markets, outdoor movies, Friday Cheers, and regional events such as music, wine tasting and art festivals.



**Revisions:**

- Walkways added throughout park.
- Central walkway widened to accommodate areas of probable congestion.
- Southern pavilion rotated and reduced in size, making it more in scale with the park and with Main Street.
- Clear sight lines and pathway through park and to amphitheater.
- Demonstration gardens completed.
- Northern patio area completed.
- Grass and concrete paver pads created to support farmer's market trucks, but public activities at other times.
- Entrances from Main Street and Grace Street revised to be pedestrian friendly and provide easy access throughout the park.
- Solar and water sculptures added relating to PSLD principles, for education.

Figure 4.5 Final design of the Smithfield Solar Park.

Figure 4.6 Legend for the final Smithfield Solar Park Master Plan.

## Smithfield Solar Park Legend

- A. North Solar Pavilion -
  - Solar voltaic roof and brick paver floor.
  - The electricity generated by the solar roof will pay for all expenses and maintenance of the park.
- B. South Solar Pavilion Building -
  - Same as the north pavilion.
- C. Cistern topped with river rock (typ.) -
  - Rain catchment system on the roof directs the rain into the cistern with a rain chain.
  - Cistern walls double as built-in seating.
- D. Smithfield Solar Educational Building -
  - Straw bale solar voltaic building.
  - contains meeting areas, restrooms, water fountains, concessions with seating areas
  - Surrounded by Passive Solar Landscape Design demonstration gardens.
- E. Misting Room -
  - Overhead misting system and trellis.
  - Allows people to feel the cooling effects of water in the landscape.
- F. Southern Patio -
  - Trellis covered paver patio provides shaded comfort in the summer.
  - Deciduous trees allow warming sunlight in during the winter, which helps to heat the building.
- G. North Patio -
  - Eating area which will be shaded during the summer.
  - Perforated walls protect against cold winter winds.
- H. Paver and grass access areas
  - Allow parking of vehicles when needed.
  - Allow public activities at other times.
  - Pavers are permeable.
- I. Concrete with pyrite embedded in the surface
  - Allows people to feel the warmth of the sun as they step on these in-ground 'rays'.
  - Rays are oriented in the north-south direction and are 37 feet apart, which is the latitude of Smithfield, and also the angle of the solar roofs of the buildings.
- J. Solar Wind Wave Lights
  - Solar-powered and sway in the wind, showing people its direction and relative velocity.
  - Lights will glow at night and be visible to signify how solar power operates the park at night.
  - All lighting in the park is solar powered.
- K. Rainfall water sculpture
  - Reflecting pool water is supplied by water from the cisterns.
  - Pump is powered from the solar voltaic system.
- L. Outdoor Movie Screen
  - 36' x 50' inflatable movie screen.
  - This will bring crowds into the Historic District, enhancing a sense of community and will increase the town's revenue.
- M. Amphitheater
  - Used for outdoor movies, performances, concerts, and many other community activities.
  - Breezes are directed into area by hedges and trees.
  - Trees planted within the seating arena provide shade.
- N. Information Kiosk
  - Movie and performance schedules, park activities and rules.
  - Concession menus will be posted here.
- O. Central Plaza
  - Public gathering spot and location of Friday Cheers.
  - Paved with crushed oyster shells
    - keeps the area cooler
    - are locally available
    - are in keeping with the atmosphere of the historic district.
  - The paving helps tie the new in with the old.
- P. Park Stroll
  - The main walkway through the park.
  - Paved in brick.
  - Ebbs and flows, connecting the pedestrian with the farmer's market pavilions as the Pagan River connects Smithfield to the James River and on to the Chesapeake Bay.
  - The stroll connects to crushed oyster shell walkways throughout the park.
- Q. Crushed Oyster Shell Walkways
  - Walkways are wide enough for people to move throughout the park comfortably.
- R. Brick Walkway
  - West entrance to the park from Main Street.
- S. Brick Retaining Wall
  - Ends in low circular pillars topped with a custom wrought iron wheat sheath sculpture which reflects the farmer's market.
  - Will display the park's activities for the month.
- T. Parking Lot
  - Crushed oyster shell paving keeps cars cool and is environmentally friendly.
  - Evergreen screening on the north side protects against cold winter winds.
  - Deciduous trees on the southern edge provide shade for cars and people.

## Solar Park Section - looking through movie amphitheater

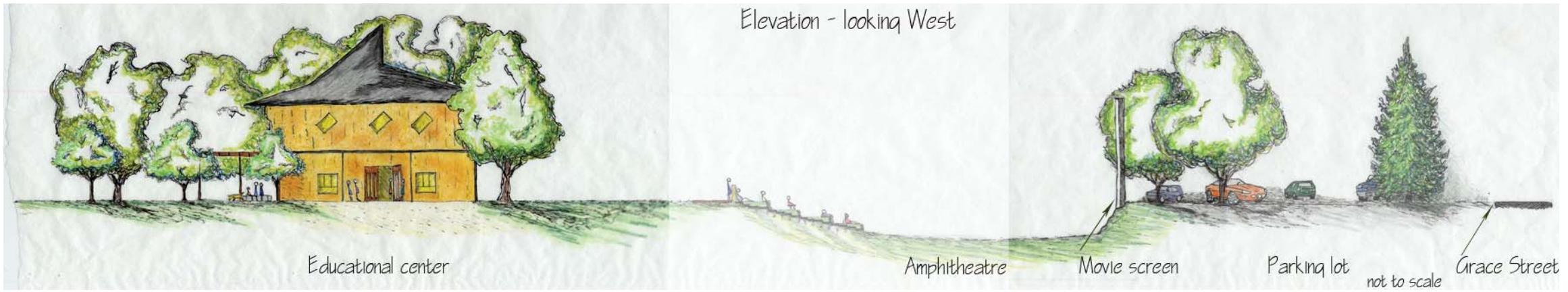


Figure 4.7 View looking west into the east side misting room of the educational center, the outdoor movie amphitheater and parking lot.



Figure 4.8 Author's initial illustration of people relaxing in the amphitheater while watching a movie or performance.

### Solar Park Educational Center Building

- Restrooms and water fountains
- Concessions for all activities
- Meeting rooms for community groups
- Outfitted with a solar voltaic system and rain catchment system.
- Self composting toilets
- Educational information sheets on all aspects of the PSLD principles and green building practices.
- North and south patios
- Generates its own electricity and the excess is sold to Va. Power, paying for yearly maintenance costs and taxes.

Breeze blowing through Smithfield Solar Park

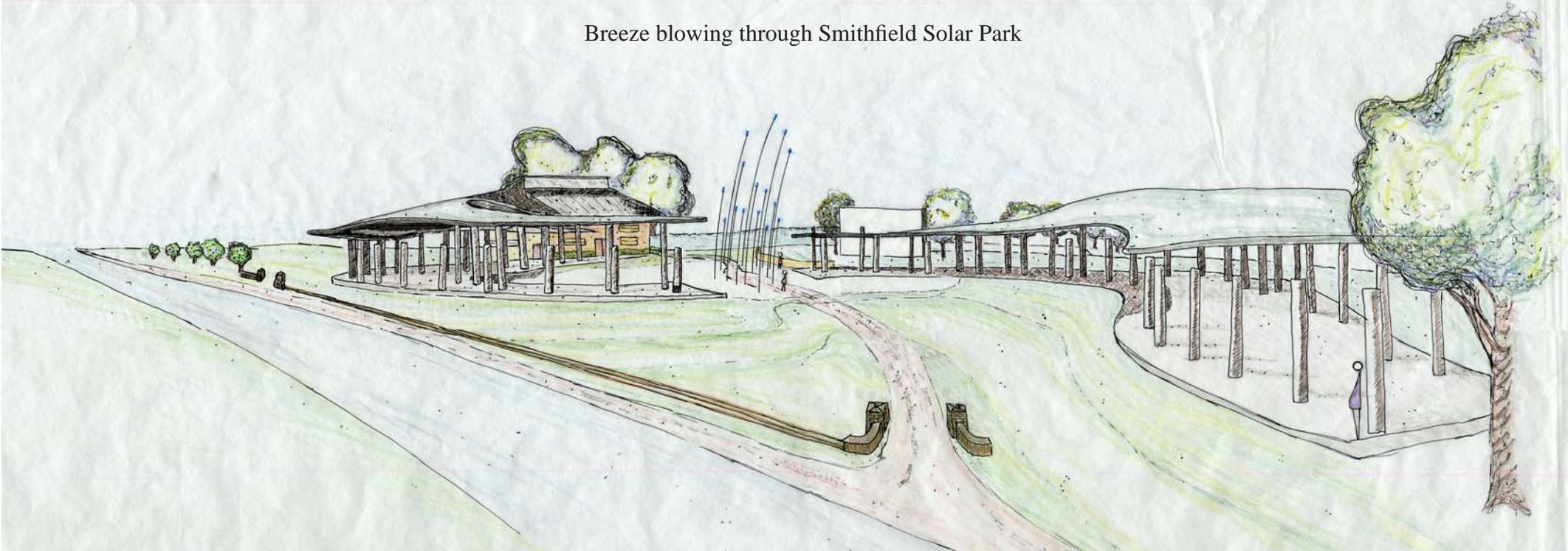


Figure 4.9 View looking west into the east entrance to the park from Main Street. The solar wave sculpture's wands bend in the breeze, indicating wind direction and relative velocity. Each wand is topped by a solar battery-powered light which will glow blue at night as a visible reminder of the sun's power, and a locating beacon for this unique landmark .



Figure 4.10 Author's depiction of crowds at the Solar Park Friday Cheers, as seen through the solar wave wind sculpture as it sways in the Pagan River breeze.

## SMITHFIELD SOLAR PARK LANDSCAPE PLANTS



Figure 4.11 Trees and shrubs to be planted in the park during seasonal Solar Park Day workdays, which will be coordinated by the Landscape committee of the Friends of Smithfield Solar Park community group.

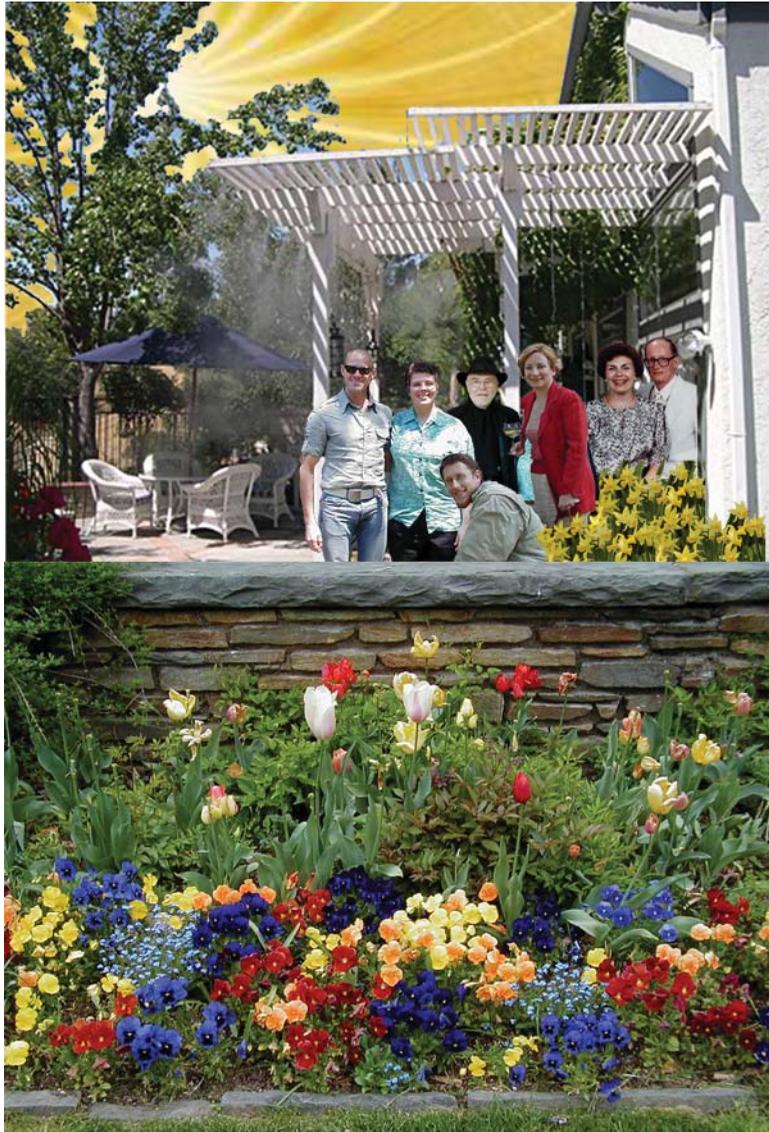


Figure 4.12 View of proposed wall and perennials on the east side of the Educational Center. The wall will help direct breeze towards the farmer's market pavilions and the amphitheater. The cooling misting room will be a welcome relief to summer visitors.



Figure 4.13 An example of a permeable fence or wall on the north side of the Education Center. This permeable structure provides a much larger area of protection from cold winter and harsh winds. This PSLD principle will enable visitors to enjoy the north patio for a longer time in the late Fall, and will reduce the heating load on the solar voltaic system powering the Center.

# Solar Park Model

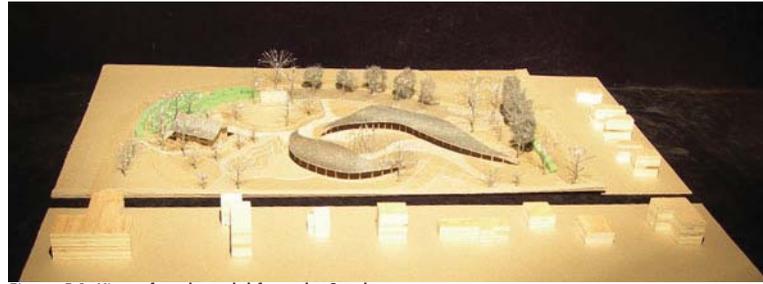


Figure 5.1 View of park model from the South



Figure 5.3 View of park model from the South showing Winter morning shadows.



Figure 5.2 View of park model from South Southwest



Figure 5.4 View of park model from the Southeast

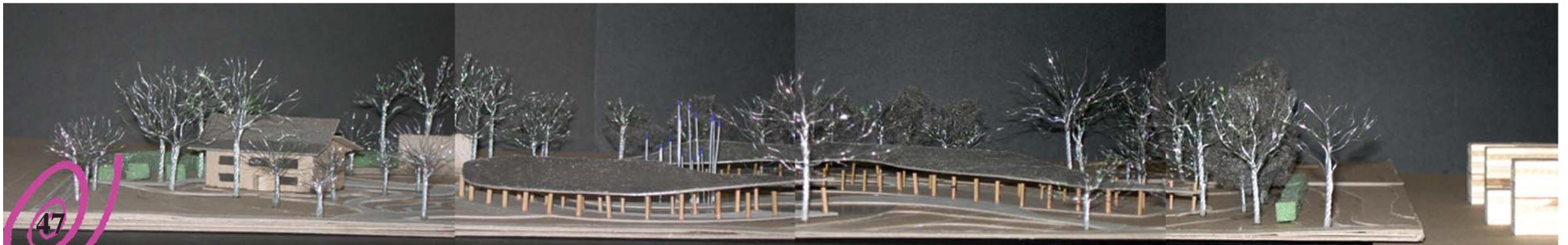


Figure 5.5 Smithfield Solar Park - view from across Main Street.

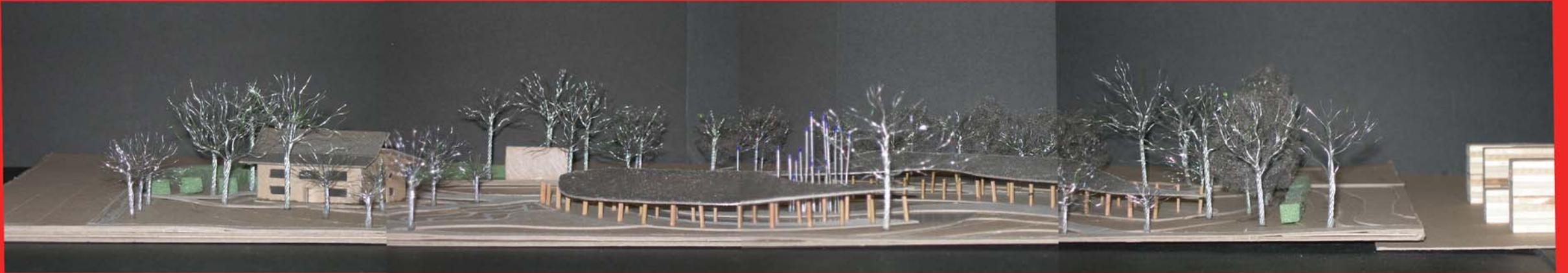


Figure 5.6 Southern view of the park highlighting the demonstration gardens, the front Farmer's Market truck entrance, the water feature and the inflatable movie screen. The model also shows how the park meets and interacts through plant life with adjacent residential properties. The green hedge on the right side marks the residential property boundary.



Figure 5.7 North Northwest view of the park highlighting the parking lot, the peeking hedges and how the park interacts with adjacent residential properties. The green hedge on the left side marks the residential property boundary.

# Smithfield Solar Park Wind Study

Month: March      Activities: Farmer's Market, others depending on weather conditions.  
Notes: Farmer's Market open stalls desirable

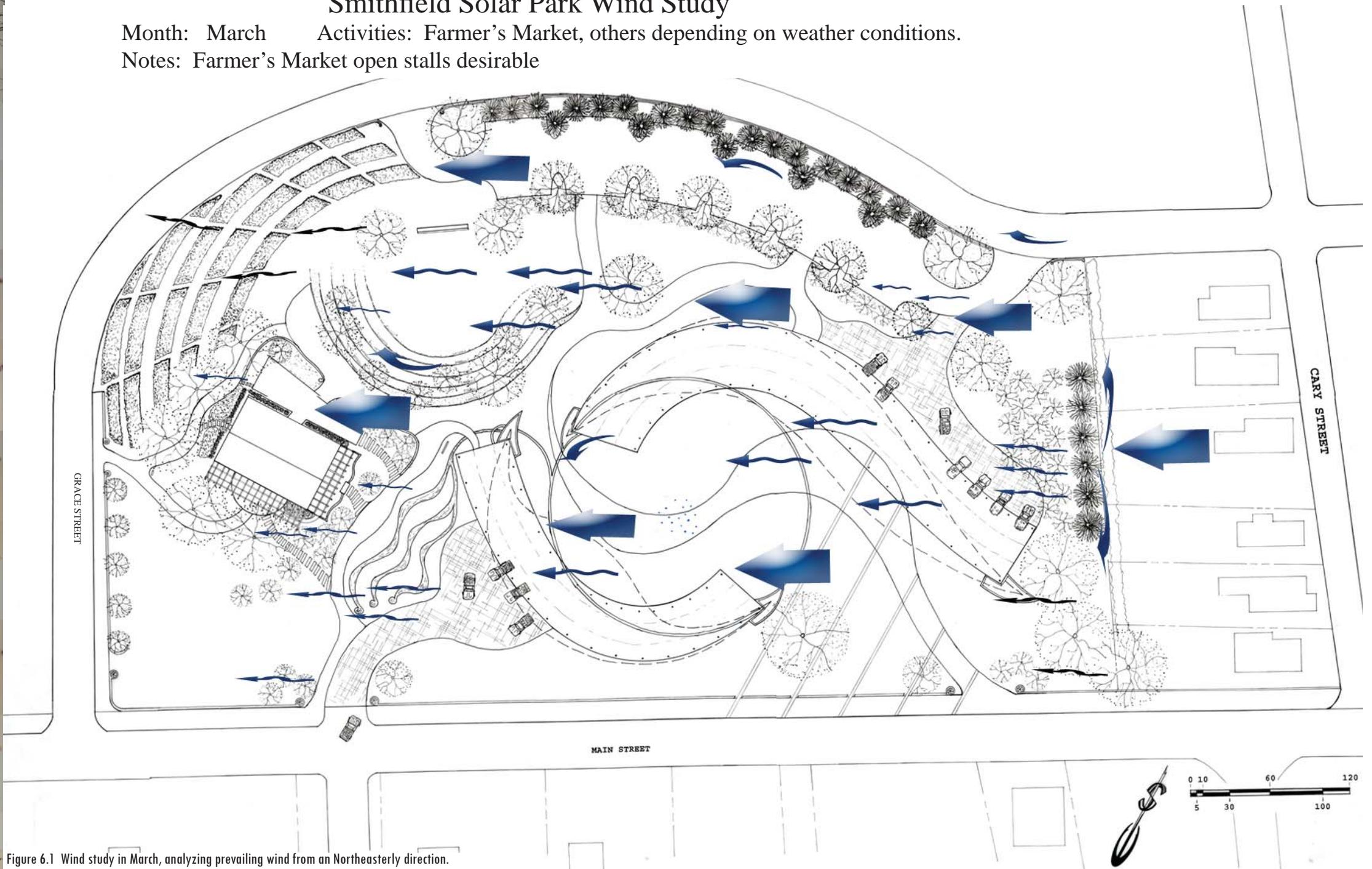


Figure 6.1 Wind study in March, analyzing prevailing wind from an Northeasterly direction.



# Smithfield Solar Park Wind Study

Month: June Activities: Farmer's Market, Outdoor Movies, Friday Cheers  
Notes: May need to supplement water feature to maintain level.

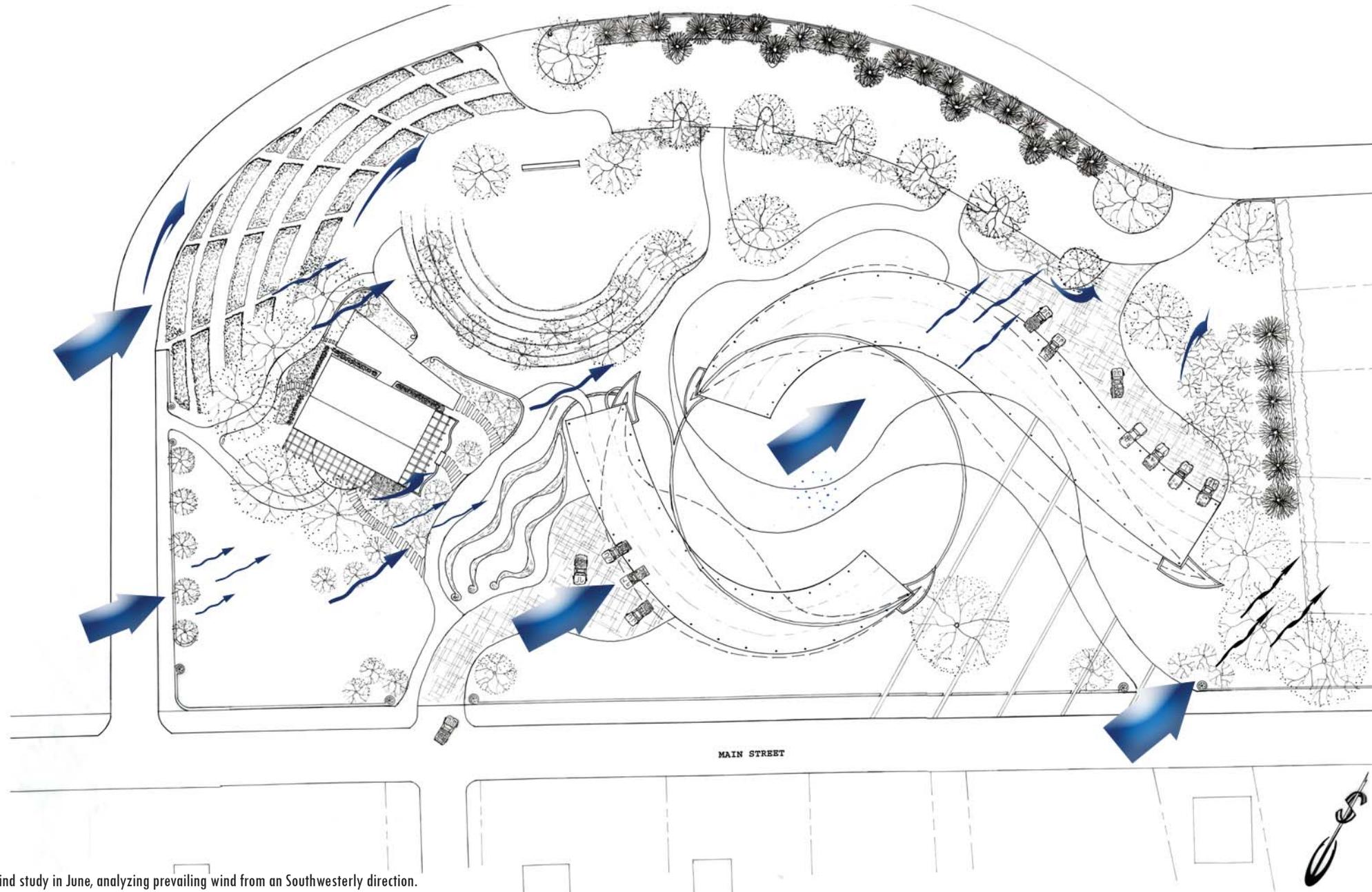


Figure 6.2 Wind study in June, analyzing prevailing wind from an Southwesterly direction.



# Smithfield Solar Park Wind Study

Month: September    Activities: Farmer's Market, Outdoor Movies, Friday Cheers  
Notes: May need to supplement water feature to maintain levels, Fall maintenance approaching.

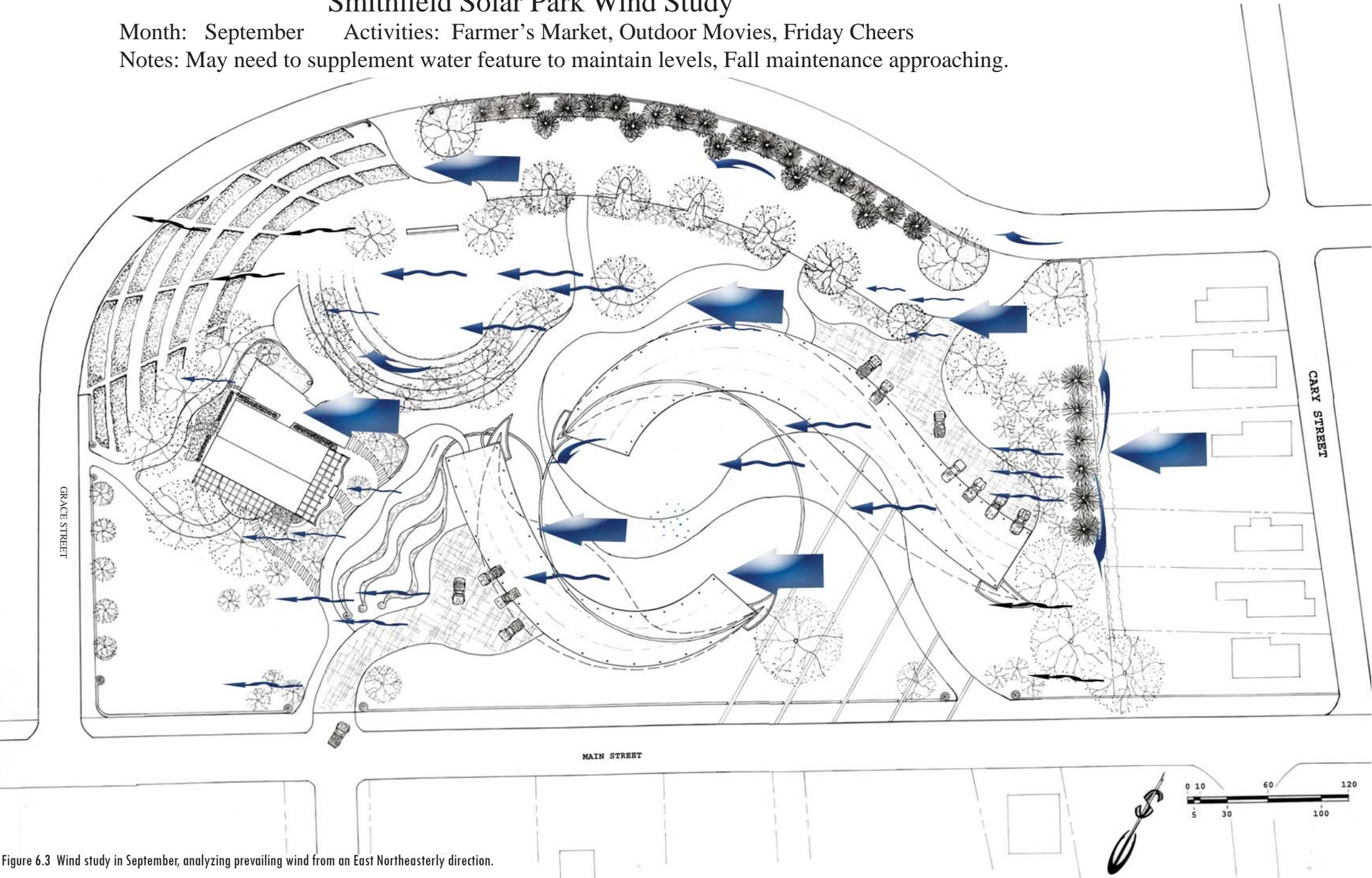
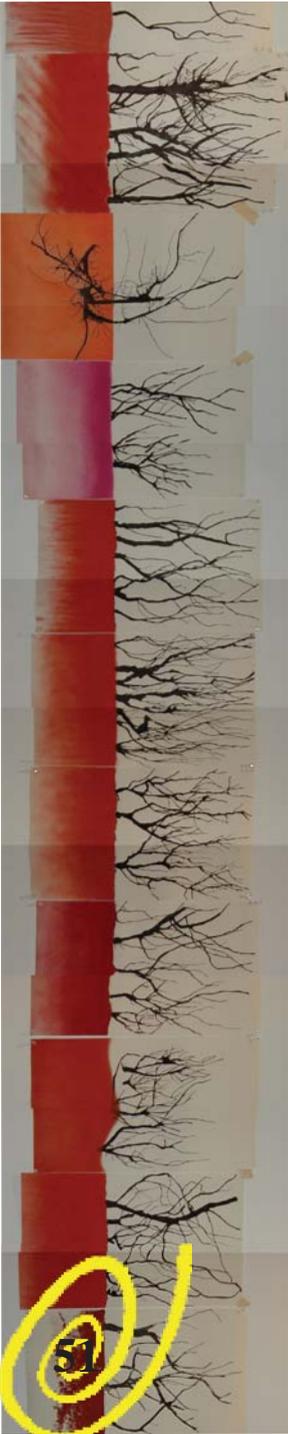


Figure 6.3 Wind study in September, analyzing prevailing wind from an East Northeasterly direction.



# Smithfield Solar Park Wind Study

Month: December    Activities: Farmer's Market, seasonal and holiday events as weather permits, utilize meeting space in educational center.    Notes: Turn on warming mechanism for water feature or drain and winterize piping.

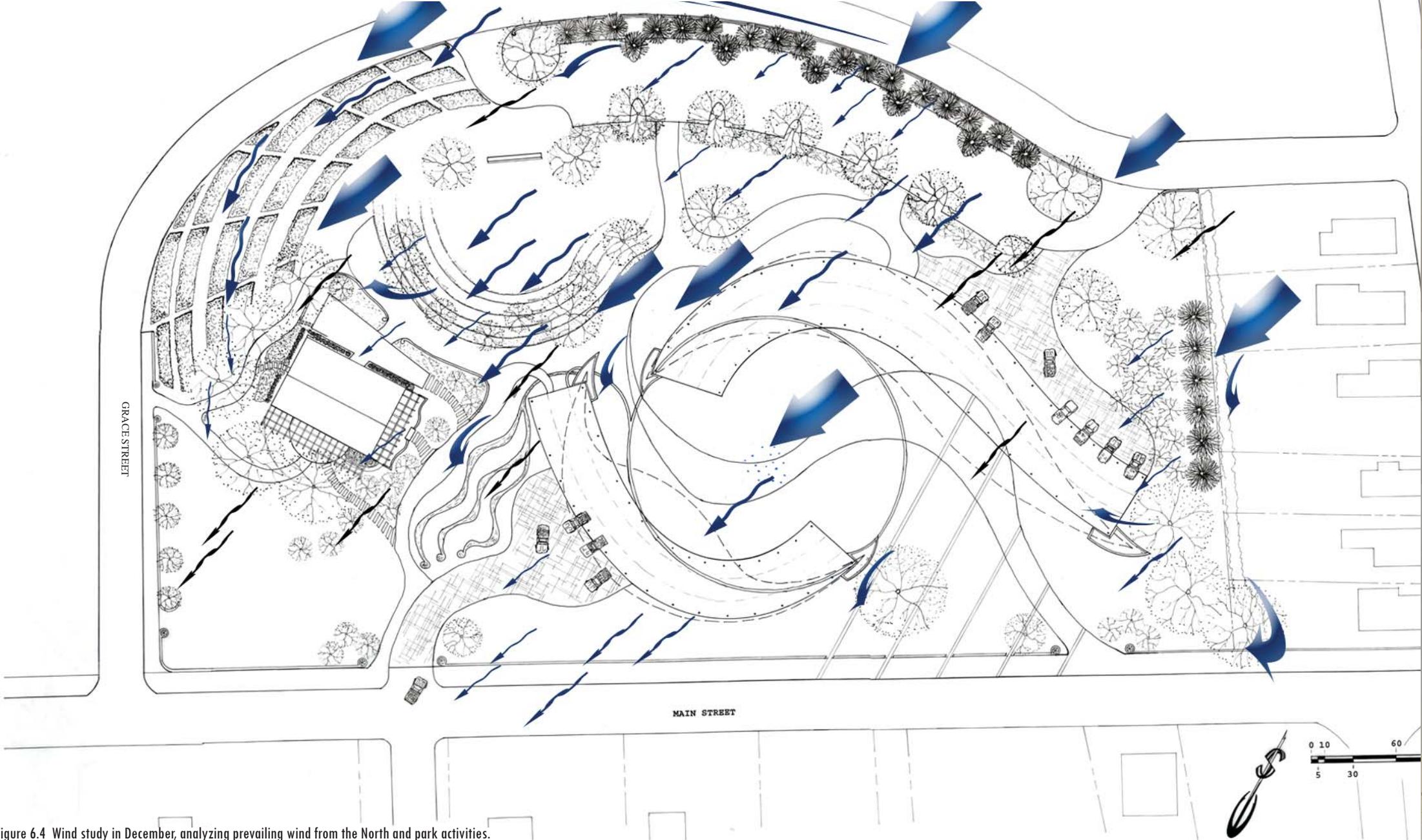
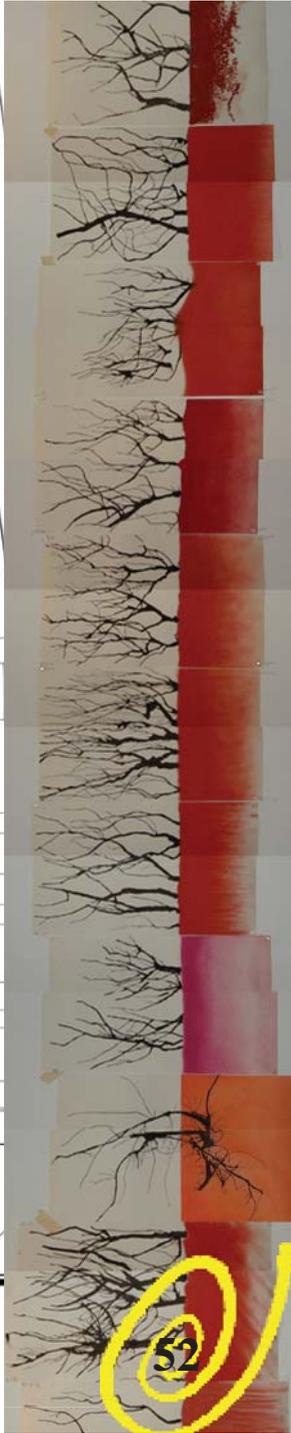


Figure 6.4 Wind study in December, analyzing prevailing wind from the North and park activities.



# Smithfield Solar Park Shadow Study

Date: March 21 and September 21, 2007. Time: 10:00 AM

Notes: Consider holding Farmer's Market in sunny areas protected from the Northeast winds.

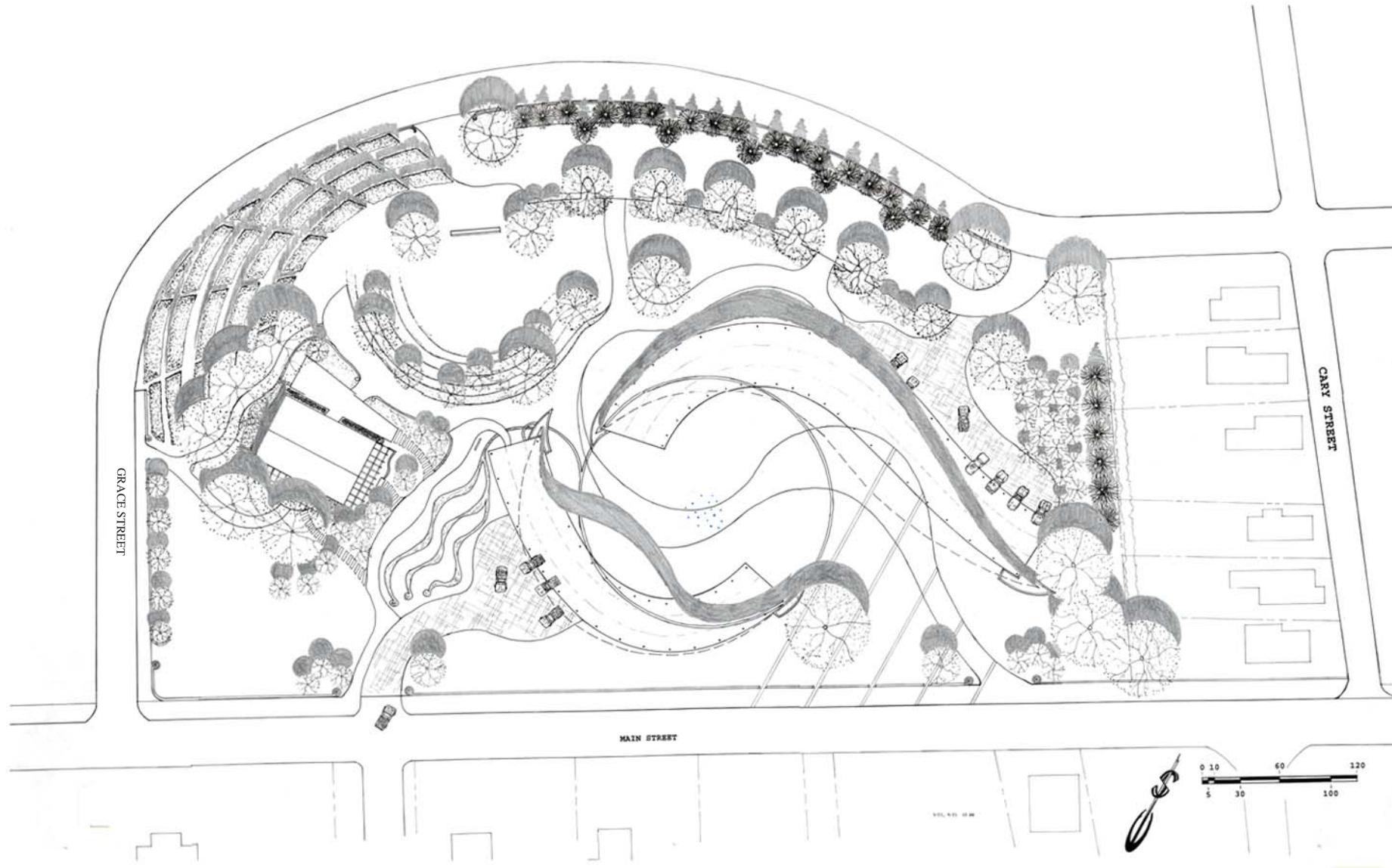


Figure 6.5 Shadow study on March 21 and September 21, 2007 at 10 AM. On these dates, the sun's azimuth and altitude are equal, respectively. In March, areas open to warming solar radiation and protected from winds should be considered for most park activities.



# Smithfield Solar Park Shadow Study

Date: March 21 and September 21, 2007. Time: 4:00 PM

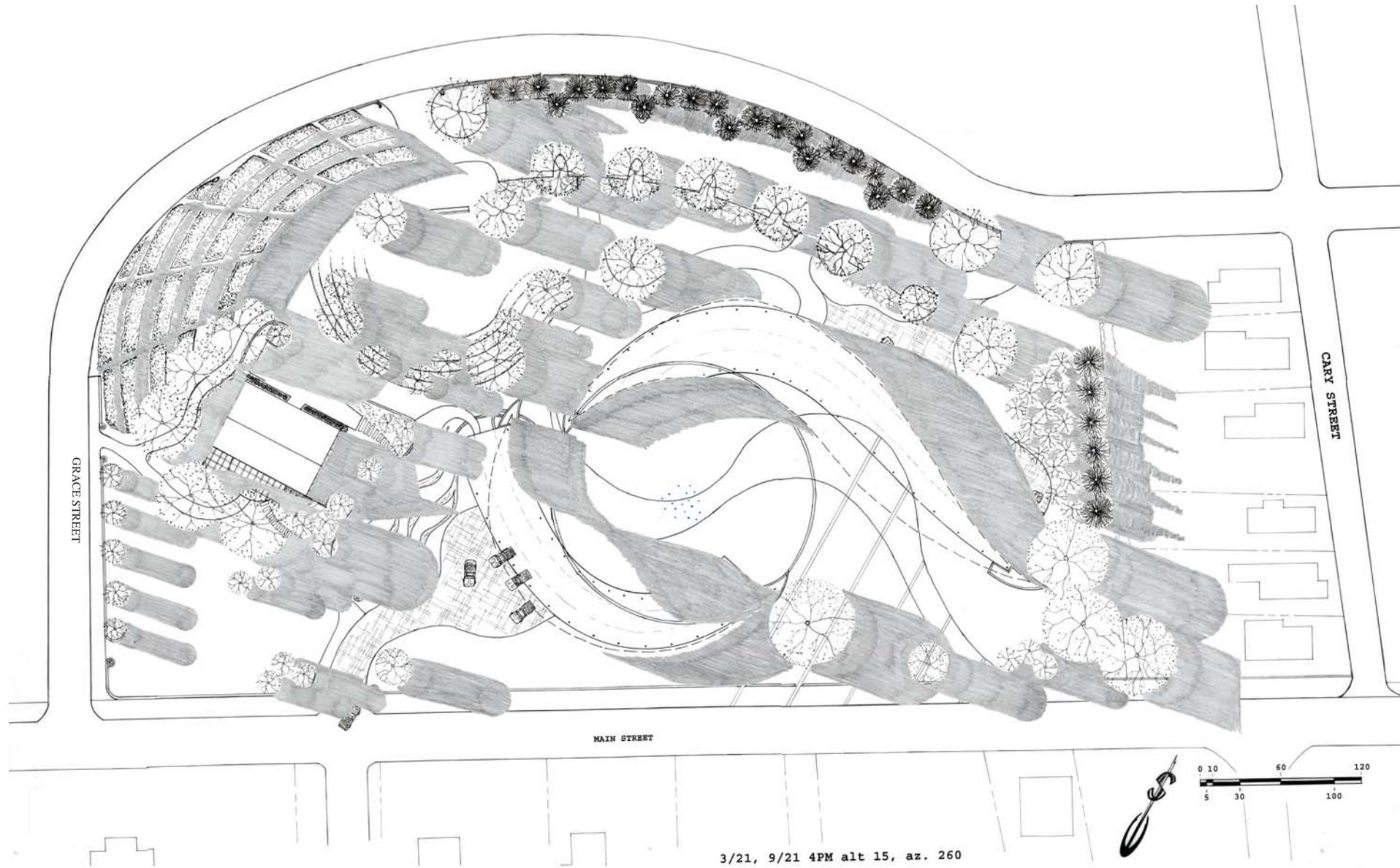


Figure 6.6 Shadow study on March 21 and September 21, 2007 at 4 PM. On these dates, the sun's azimuth and altitude are equal, respectively. In March, areas open to warming solar radiation and protected from winds should be considered for most park activities.



# Smithfield Solar Park Shadow Study

Date: June 21, 2007. Time: 10:00 AM

Notes: Shaded stalls may be preferred for Farmer's Market.



Figure 6.7 Shadow study on June 21, 2007 at 10 AM. Shaded areas will be preferred for most activities. Portable shade devices such as umbrellas will be used in sitting and eating areas throughout the year, as needed.

# Smithfield Solar Park Shadow Study

Date: June 21, 2007. Time: 4:00 PM

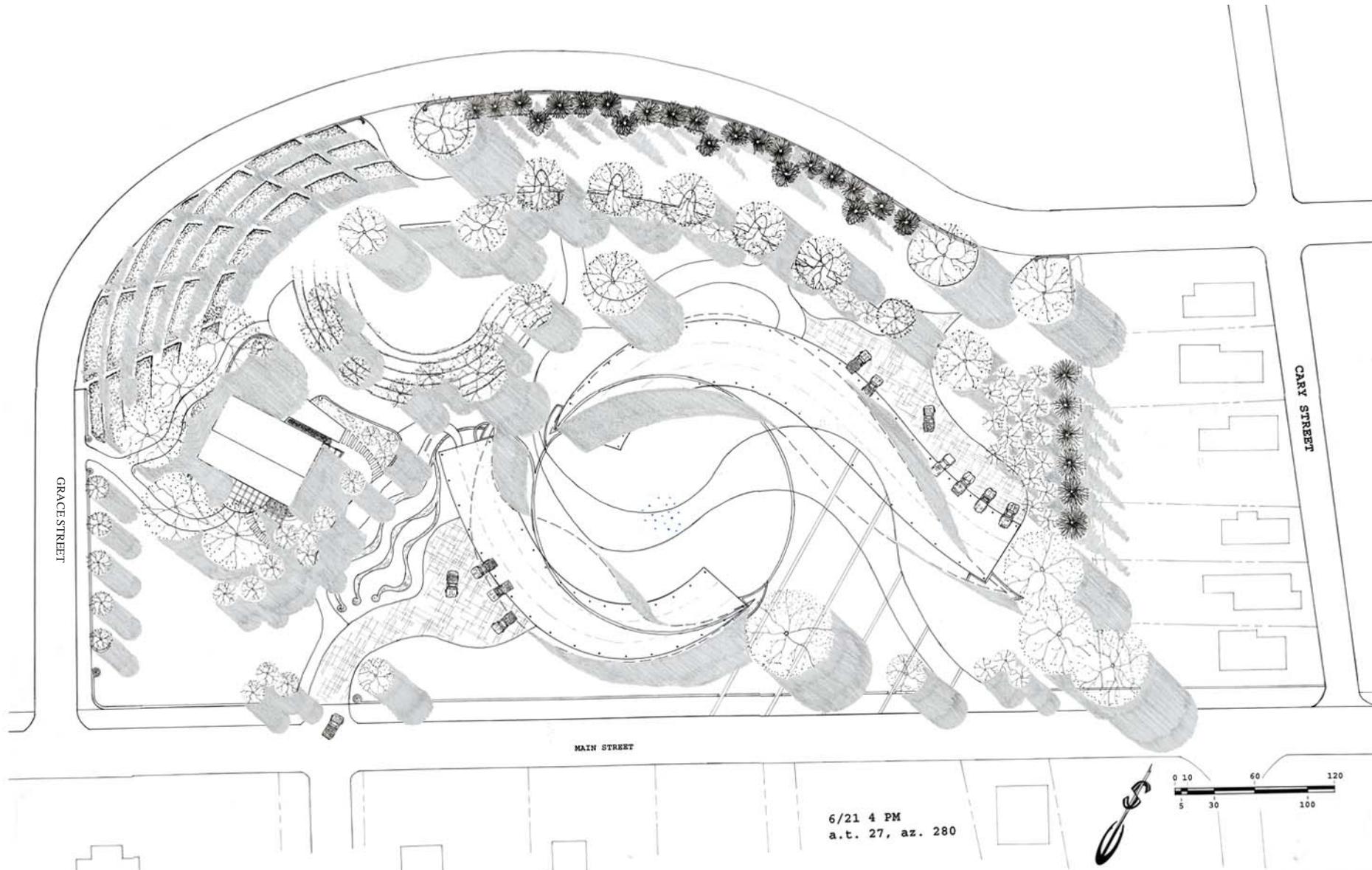


Figure 6.8 Shadow study on June 21, 2007 at 4 PM. Shaded areas will be preferred for most activities. PSLD education is ongoing and seminars and classes will be offered to the public.



# Smithfield Solar Park Shadow Study

Date: August 1, 2007. Time: 10:00 AM



Figure 6.9 Shadow study on August 1, 2007 at 10 AM. Shaded areas will be preferred for most activities.

# Smithfield Solar Park Shadow Study

Date: August 1, 2007. Time: 4:00 PM

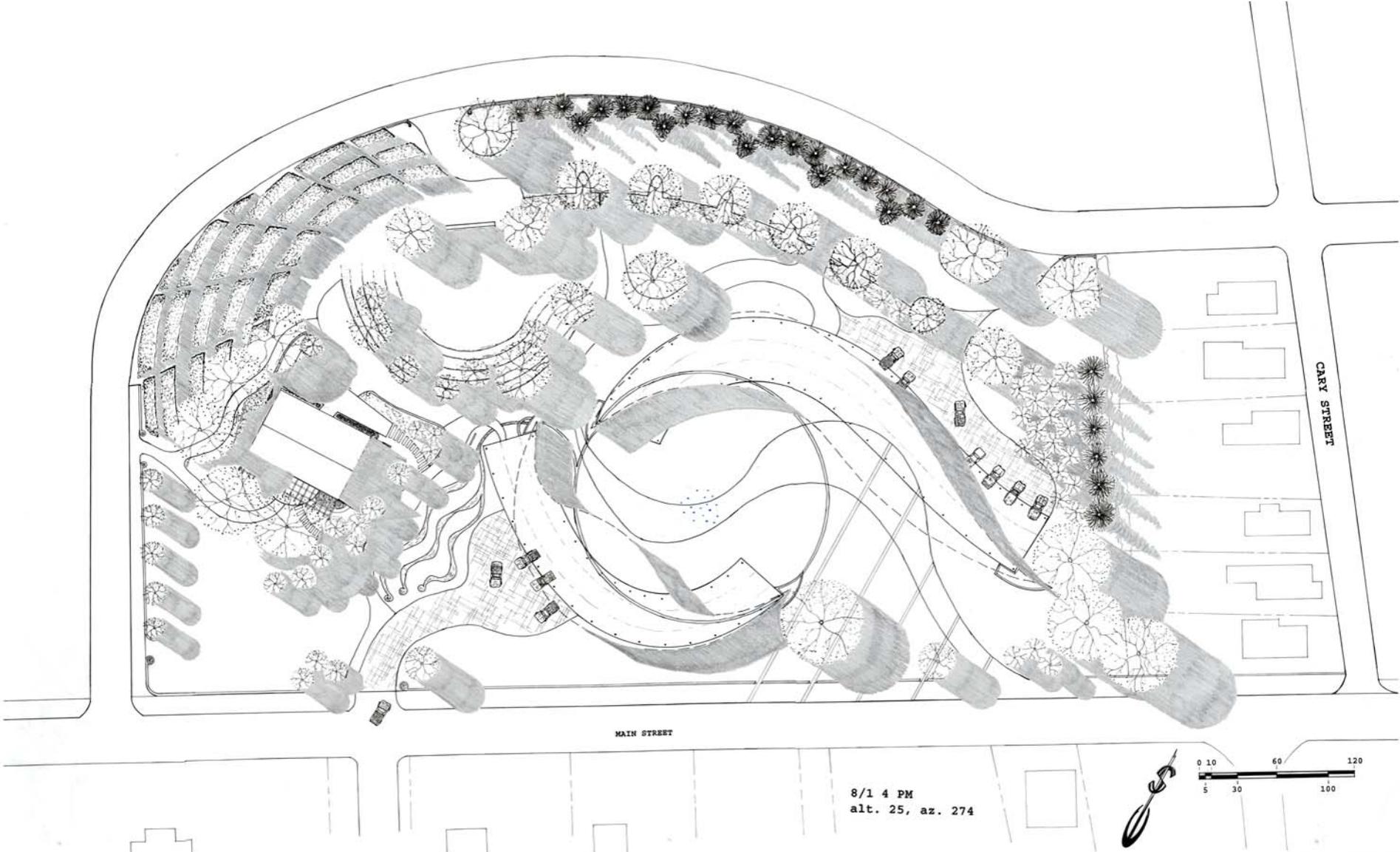
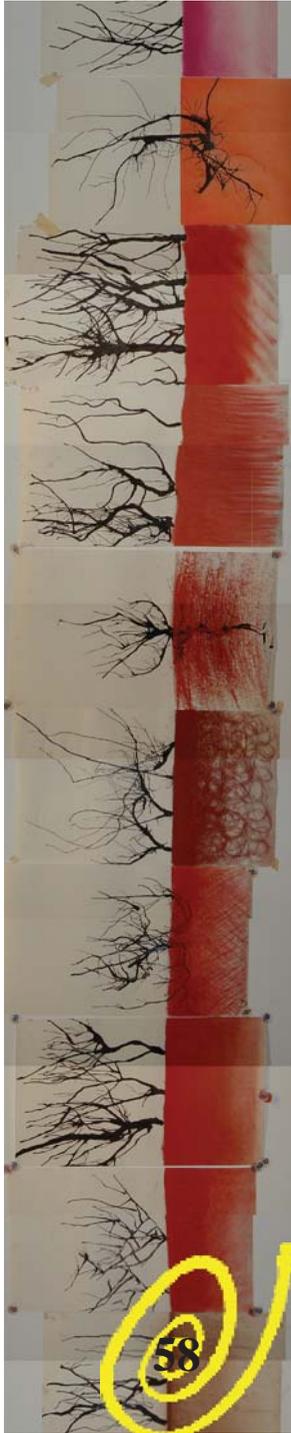


Figure 6.10 Shadow study on August 1, 2007 at 4 PM. Shaded areas will be preferred for most activities. Portable shade devices such as umbrellas will be used in sitting and eating areas.



# Smithfield Solar Park Shadow Study

Date: December 21, 2007 Time: 10:00 AM

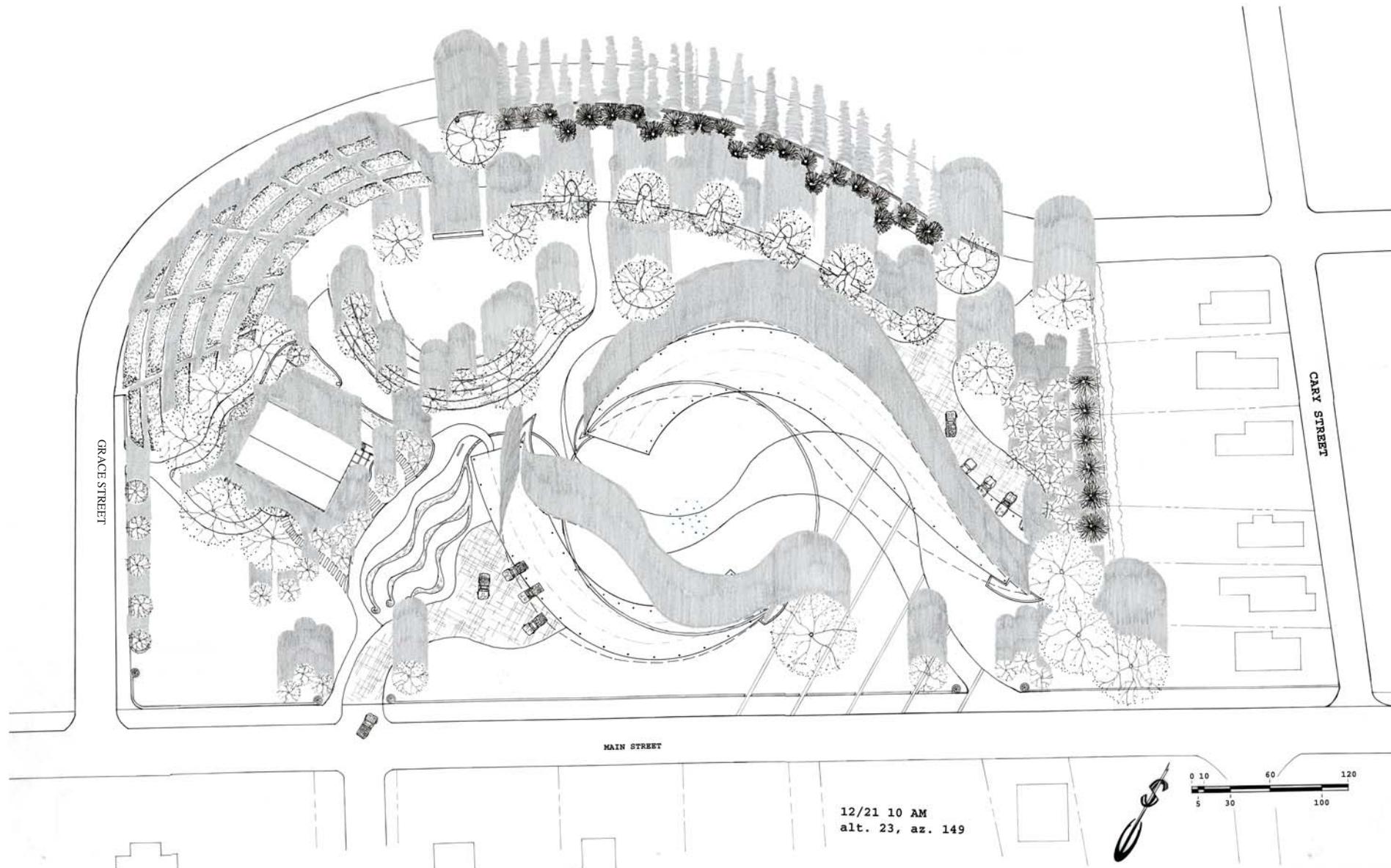


Figure 6.11 Shadow study on December 21, 2007 at 10 AM. Sunny areas protected from cold winds will be preferred for most activities. Seasonal activities will take place as weather conditions permit. PSD and solar voltaic system education classes will be offered.

# Smithfield Solar Park Shadow Study

Date: December 21, 2007 Time: 4:00 PM

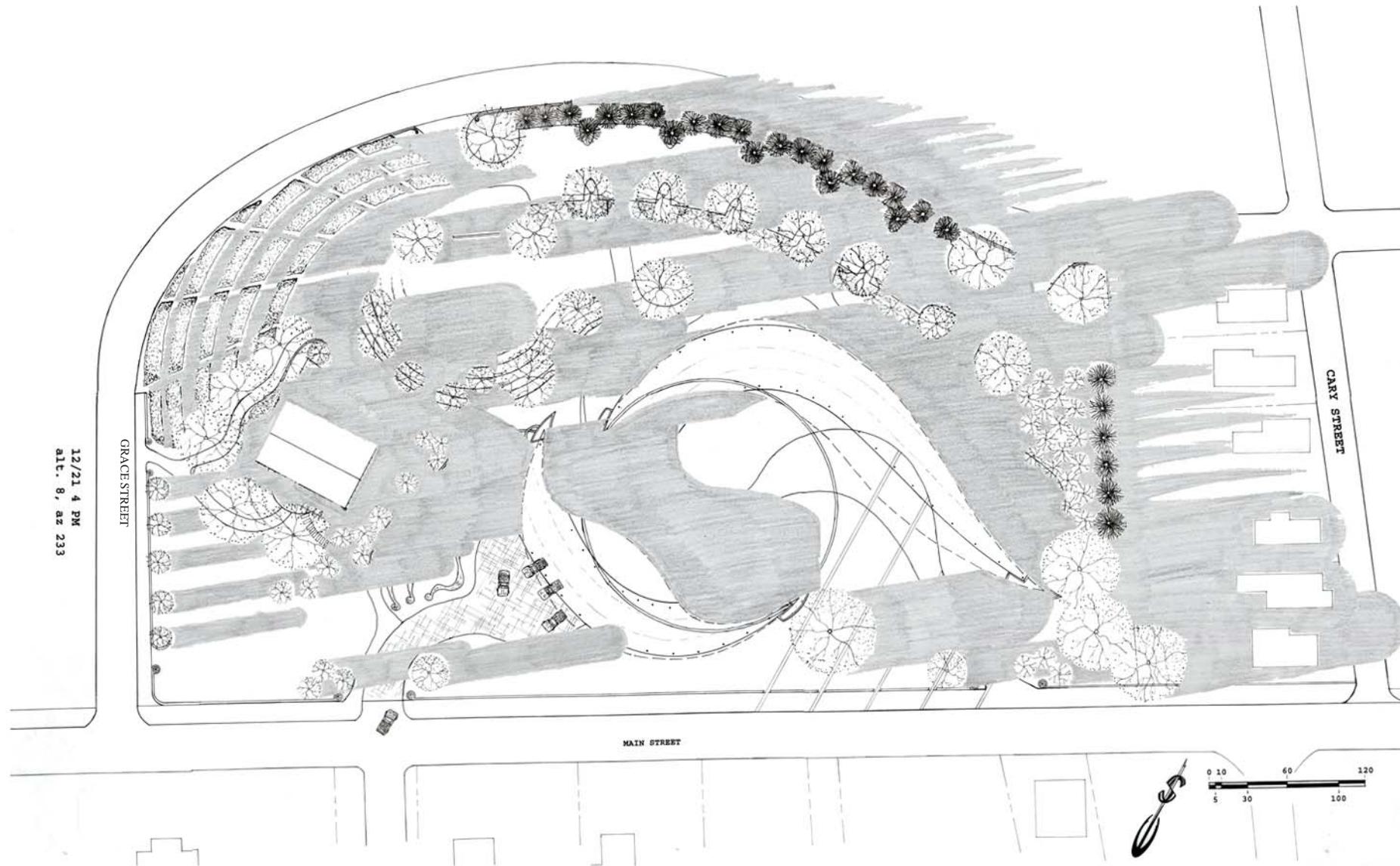


Figure 6.12 Shadow study on December 21, 2007 at 4 PM. Areas protected from cold winds will be preferred for most activities. Seasonal activities will take place as weather conditions permit.



# Smithfield Solar Park In Spring



Figure 6.13 Smithfield Solar Park in spring. Activities include Farmer's Market, movies under the stars, Friday Cheers and community events. PSLD education will be a major visitor attraction as the planting season begins.

# Smithfield Solar Park In Summer



Figure 6.14 Smithfield Solar Park in summer. Activities continue from the spring season. PSLD education is ongoing.



## Smithfield Solar Park In Fall



Figure 6.15 Smithfield Solar Park in fall. Activities include Farmer's Market, movies under the stars, Friday Cheers and other outdoor events as weather permits. PSLD and solar voltaic education classes are held for the public throughout the fall and winter.

# Smithfield Solar Park In Winter



Figure 6.16 Smithfield Solar Park in winter. Educational activities, both indoor and outdoor continue as weather permits.





Figure 6.17 Smithfield Solar Park at night in spring.



Figure 6.18 Smithfield Solar Park at night in summer.





Solar Park at Night - Fall

Solar Park in Fall

Figure 6.19 Smithfield Solar Park at night in fall.



Figure 6.20 Smithfield Solar Park at night in winter.





## Conclusions

Designing Smithfield Solar Park was exciting, exhausting, and an endless source of activity for my brain as I tried to fall asleep at night.

As with Mother Nature, the principles of PSLD intertwine and are in a symbiotic relationship with each other. When I added different activities at various times of the day and year into the mix, I quickly realized that every design decision had to be carefully thought out and tried. I would try an idea only to find that it impacted other PSLD principles unexpectedly or that it was itself impacted by the next idea, necessitating revisions. I found that simply sitting back and collecting my thoughts or discussing ideas with my committee or classmates would bring everything back to clarity and the design moved forward again. Building a model was the most productive aspect of the design, and it allowed me to become a visitor in the park, and see from the ground plane how the sun, shade, and wind moved through the landscape.

Looking back, viewing the park as a whole instead of as separate pieces was key to having all of the PSLD principles working in harmony. I hope that my thesis project can be used as a guide for landscape architects and homeowners alike to implement PSLD into existing or future landscapes.

Although I enjoyed reading the books and articles about solar energy issues, I had no idea that there was so little information dedicated to PSLD. Most of the information that I read concerns the solar aspects of architectural buildings. This is very important when implementing avenues of fossil fuel reduction, but more projects and articles need to focus on the issue from the landscape architecture side.

I think that the major obstacle to PSLD

implementation into all landscapes is the general public's lack of education on the subject, its importance and how it can benefit them. People seem to automatically label anything solar as complicated, technical and expensive, not to mention the expense, work and maintenance of a designed landscape.

The town of Smithfield would greatly benefit from building the Solar Park, which is designed to be built by the people and businesses of the area. People need to have a place where they can experience and enjoy what we are trying to inform and educate them about, not simply read a brochure. The economy of the area would grow, tourism would increase and the community would have a place to meet and interact.

I feel that we have been slow to implement PSLD, and have relied too heavily on fossil fuel consumption for energy, but we are beginning to turn this tragedy around. It is up to us, as upcoming landscape architects, to educate the public and government about the numerous benefits of PSLD, and to incorporate these principles into our designs. Landscape architecture has a share of the responsibility for the future health of our planet – let us accept it and make a difference.

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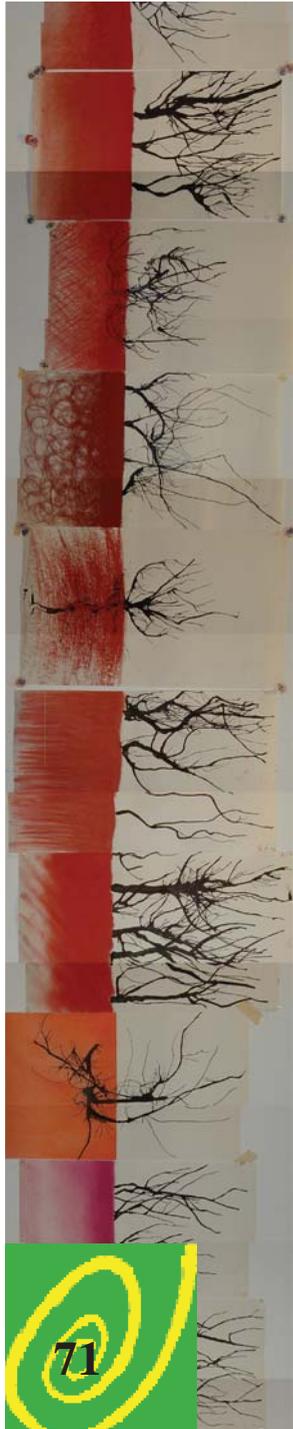
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## **Robin Wiatt Boelt**

### **EDUCATION**

Master of Landscape Architecture, Virginia Polytechnic Institute and State University, 2006.  
Landscape Design Certificate, George Washington University, 2004.  
Woody Plants Certificate, George Washington University, 2003.  
AutoCad I & II and 3ds Max 5, J. Sargeant Reynolds Community College, 2004.  
Associate, Registered Nurse, University of New York, Albany. 1996.  
B. A. Biology, Christopher Newport University, 1992.  
National Registry EMT-Paramedic, Medical College of Virginia, 1992.  
Engineering/Nuclear Submarine Design, Newport News Shipbuilding & DryDock Company, January, 1985 – May, 1987.

### **SKILLS**

Landscape Design: Certified Landscape Designer and sole proprietor of a successful custom landscape design business, designing residential and commercial properties, offering a full range of design services including cost estimating and installation supervision. Create Master Plans based on clients' personal preferences, budgets and extensive research. Other projects include the Practice Tee at Lake Chesdin Golf Course and the marketing image for the Bank of Southside Virginia.  
Computer Skills: AutoCad 2006, PhotoShop CS2, In Design CS2, Flash 5.0, 3ds Max 5.0, Microsoft XP Pro, MS Office (Word, Excel, Access, PowerPoint), and Internet.

### **EXPERIENCE**

President, The Gardener Of Eden Landscape Design, LLC, Powhatan, Va. - Jan. 2002 – Dec. 2005.  
Responsible for start-up, sales, marketing, planning and financial administration of business. Obtained 65 clients, and maintained ongoing designer/client relations.  
Promoted business through advertising, referrals from satisfied clients, trade shows, and network interaction with area landscape professionals. Prepared design contracts, bids, proposals, and handle negotiations in securing projects and accounts in the residential market. Provided project coordination with selected vendors and clients.  
Custom landscape design and installation supervision:

- Creation of master landscape plans, both hand and AutoCAD rendered
- Specification of trees, shrubs, ground covers, perennials, annuals, bulbs, sodding and seeding
- Working with contractors on grading, drainage and irrigation plans, layouts and construction details.

Worked closely with area subcontractors to obtain plant and building materials, to construct and install the projects properly, and to ensure high quality goods and services.

### **PROFESSIONAL AFFILIATIONS**

Certified Landscape Designer by Virginia Society of Landscape Designers, Certification # 066  
Student Member, American Society of Landscape Architects  
Member, Virginia Nursery and Landscape Association  
Member, Powhatan Chamber of Commerce  
Member, Central Virginia Better Business Bureau

### **VOLUNTEER AFFILIATIONS**

Numerous VSLD educational booth and Maymont projects  
George Washington University Maymont booth  
curriculum vitae

