A SYNERGISTIC APPROACH TO OUTDOOR LIGHTING DESIGN:

REVISION OF THE OUTDOOR LIGHTING AT UGA EAST CAMPUS VILLAGE

by

LIAN Z. LI

(Under the Direction of Bruce K. Ferguson)

ABSTRACT

Outdoor lighting is an integral part of the design in the landscape and the built environment. It is what keeps places alive with people at night. Many outdoor lighting installations we experience at night, however, are uninformative, wasteful, unsafe and monotonous. This thesis takes a synergistic approach to investigate lighting issues that are directly linked to light pollution, Crime Prevention Through Environmental Design and wayfinding by reviewing current outdoor lighting design criteria and requirements, to form a set of design guidelines that can be applied in the three revisions to East Campus Village's lighting design on UGA campus.

INDEX WORDS: outdoor lighting design, light pollution, Crime Prevention Through Environmental Design (CPTED), wayfinding, light source, luminaire, illuminance, luminance, energy efficient lighting

A SYNERGISTIC APPROACH TO OUTDOOR LIGHTING DESIGN:

REVISION OF THE OUTDOOR LIGHTING AT UGA EAST CAMPUS VILLAGE

by

LIAN Z. LI

B.S., Syracuse University, 2000

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF LANDSCAPE ARCHITECTURE

ATHENS, GEORGIA

2011

A SYNERGISTIC APPROACH TO OUTDOOR LIGHTING DESIGN:

REVISION OF THE OUTDOOR LIGHTING AT UGA EAST CAMPUS VILLAGE

by

LIAN Z. LI

Major Professor: Bruce Ferguson

Committee: Georgia Harrison
Anne Sweaney
Jay Wansley

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
August 2011

ACKNOWLEGEMENT

First and foremost, I want to thank Professor Bruce Ferguson, my major professor for his invaluable guidance and advice. He has kept me on track and motivated throughout this process. Second, I would like to thank the members of my Reading Committee, Georgia Harrison, Anne Sweaney, and Jay Wansley for taking the time to review this thesis and offer their comments. Third, I want to thank my classmates/friends for their support, encouragement and friendship in the past three years. Finally, I want to thank my family for their unconditional love and support.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

CHAPTER 1

INTRODUCTION

Outdoor lighting has become an essential and inseparable part of our night landscape, and to our modern life. It has helped us to see, function and enjoy things that we wouldn't be able to otherwise at night, but some outdoor lighting installations we experience today are uninformative, wasteful, unsafe and dull. As the night becomes more artificially brightened, many problems start to arise as well. Light pollution, "a by-product of outdoor lighting" ("Light Pollution" 1), wastes enormous amounts of energy; generates million of tons of greenhouse gases; disrupts ecosystems; threatens wildlife; puts public health and safety at risk; and threatens to destroy one of our most ancient and treasured universal cultural values. Living in total darkness at night is simply not an option for most of us because of how much dependency we have on outdoor lighting. One important function of outdoor lighting is to help us navigate from place to place at night; but careless design and misplacement of the lights can often lead to confusion and distraction. Well-designed outdoor lighting can be used as a device for wayfinding and to provide visual cues at night. Another important function of outdoor lighting is to provide security and safety at night. Our common belief is that bright lights enhance public safety; however, to the contrary, studies have shown that brightly illuminated areas with a dark perimeter are less safe than the same areas without having any artificial light source because both glare and shadow created by the light can severely obscure our vision (“Outdoor Lighting and Safety”). What needs to be done is to create design solutions that not only will reduce the actual risk of crime but also the fear associated with it. What do outdoor lighting designs need to encompass in order to minimize light pollution, while simultaneously meet lighting requirements and demands presented in wayfinding and Crime Prevention Through Environmental Design (CPTED)?

The Illuminating Engineering Society of North America (IESNA) has identified some issues that need to be taken into account when designing lighting for outdoor applications. These issues include glare, luminance, visual acuity and illuminance (IESNA RP-33-99 1-3). Some of these issues will be discussed more in detail in chapter 2.

This thesis will take a synergistic approach to investigate the issues concerning outdoor lighting that are directly linked to light pollution, wayfinding and CPTED. Although, lighting design recommendations have been made to solve some problems presented in each of these three areas separately; no attempt has been made to look at all three areas simultaneously. For example, a lighting recommendation that works well to preserve the dark skies might not work for a situation in which lighting is needed for navigation and security purposes. The intent of outdoor lighting design should strive for creating quality and effective lighting which will minimize light pollution and its negative impacts, conserve energy, meet the needs of wayfinding, and increase public safety. It’s important to take light pollution, wayfinding and CPTED into account when choosing possible design solutions and alternatives to meet lighting criteria for any application because only then can the design intent be fully realized. This thesis is only for the use of outdoor applications that involve nighttime activities and users.

The purposes of this thesis are to: (1) through literature research, review and synthesize current outdoor lighting design criteria and requirements for light pollution, CPTED and wayfinding; (2) explore energy efficient lighting technologies that will offer improved supply; (3) review the current outdoor lighting at UGA East Campus Village and make alternative design proposals, so that the overall lighting quality can be improved for a community where four student residence halls is located; (4) evaluate what types of revisions to East Campus Village's lighting design are found advantageous, and consequently what types of improvements could be called for in future design practice.

CHAPTER 2

LIGHTING REQUIREMENTS AND RECOMMENDATIONS

Introduction

This chapter will first review outdoor lighting design criteria and requirements for light pollution, CPTED and wayfinding separately. Then the lighting criteria and requirements from all three areas will be synthesized to form a design guideline which can be used for various outdoor lighting applications to simultaneously address the lighting issues and challenges presented in light pollution, CPTED and wayfinding.

Light Pollution

Light pollution caused by excessive and obtrusive artificial lighting at night has increasingly become one of the major pollutions that we are facing today. The most commonly-known forms of light pollution include sky glow, glare and light trespass ("Light Pollution" 2).

There are many sources that contribute to sky glow, including both natural and human-made ("Light Pollution" 3). For the purpose of this thesis, only human-made sources are considered. Sky glow happens when light accumulated from poorly designed outdoor lighting and reflected from well-directed surfaces of lit objects, such as roads, paths and buildings is being projected upward and reflected and scattered by dust, water vapor and other particles into the atmosphere, creating a light dome over cities and towns, that can be seen from hundreds of miles away. Sky glow can severely interfere and obstruct the observations of the night sky by astronomers and other night sky viewers (IESNA RP-33-99 9). Glare occurs when a bright light source overwhelms everything else in the field of view, making it difficult or impossible to see. Glare can be disabling and discomforting. Disability glare occurs when excessive bright light shines directly into the eye, causing reduced visibility to perform a task. Discomfort glare is a sensation of discomfort induced by high contrast or a non-uniform distribution of illuminance in the field of view (Narisada and Schreuder 295-315; IESNA 21-1). Light trespass occurs when unintended and unwanted light spills over someone else's property and living space; e.g. a strong bright light from a nearby parking lot shines into someone's bedroom window at night causing sleep disturbance and discomfort (Narisada and Schreuder 160-70). Poorly designed unshielded floodlights, high wattage pedestrian lights and other unshielded luminaries are the main sources that cause light trespass (Watson, Plattus, and Shibley, 7.10-3).

According to the statistic provided by the International Dark-Sky Association (IDA), an estimated 30% of outdoor lighting – plus even more indoor lighting, is wasted. In developed nations, the wasted outdoor lighting cost is about 2.2 billion dollars a year; and the amount of carbon dioxide produced by generating electricity is about 38 million tons a year, a major contributing factor to global warming ("Light Pollution and Energy" 2). A recent study presented at the

Geophysical Union meeting in San Francisco indicates that excessive artificial lighting at night exacerbates air pollution. Bright lights in the cities can slow down a natural air cleansing process in which a form of nitrogen oxide actually breaks down the chemicals released from air pollutants during the day in the darkness of the night time, hence further compromising the air quality (Klotz).

Artificial lighting can be very disorienting for animals that are active at night. It interferes with their natural rhythm to mate, to hunt, to rest, and to move at night. There are many incidents of migratory birds flying into lighted buildings and towers because the lights on these structures disrupt their inborn ability to navigate in the darkness. Studies show that approximately 100 million birds a year die in collisions with lighted buildings and towers throughout North America. Disorientation from artificial lighting causes thousands of sea turtle hatchlings' deaths each year in Florida. Naturally, the hatchlings move toward the ocean where light is reflected from the stars and the moon. In the case of high intensity artificial lighting from the neighboring beachfront communities, instead of the ocean, the hatchlings are more likely to travel in the wrong direction where the artificial lighting is. They often end up dying from dehydration, exhaustion and sometimes getting killed by cars ("Light Pollution and Wildlife" 1-2). Artificial night lighting also disrupts the function of photoreceptors that have been acquired by plants over the course of evolution, thus affecting the development processes of many plants. These processes include seed germination, stem and leaf growth, flowering, fruit development, cessation of leaf production, and leaf senescence and abscission (Rich and Longcore 397-405). These are just a few examples of how much negative impact light pollution could have on plants, wildlife and their habitats.

In the past 20 years, researchers have been studying the link between artificial lighting and breast cancer. The findings are yet being published, but are astounding enough to give us all a wakeup call. Women, such as nurses who work night shifts, have high breast cancer rates. Experts believe that long term exposure to artificial lighting at night interrupts the state of circadian system by suppressing the body's natural production of the hormone melatonin which has cancer fighting properties. A new study found that breast cancer incidence is about 73% higher in areas with the greatest amount of artificial light at night than in areas with the least (Fleming; Stevens). Even though the chance of developing breast cancer is more prevalent in the case of being mainly exposed to indoor artificial lighting, exposure to unwanted outdoor lighting produced by light trespass through bedroom windows can be equally critical. It can cause sleep disorders in people, and severely impair their performance at work during the day.

The night sky has had great influence on many different cultures and religions throughout human history. For thousands of years, the dark sky has always been observed, celebrated, written about, studied, worshiped, and mystified. It gives us a sense of wonder and perspective of how our own planet is related to the rest of the universe ("Lightscape / Night Sky"). Now we can only see a handful of stars on a clear night because the sky glow caused by excessive artificial lighting looms over cities and towns stealing the beauty and magnificence of our night sky. A study shows that more than 2/3 of the population in the United States cannot see the Milky Way from where they live and 99% of the population lives in an area that scientists consider light polluted ("Natural Lightscape Management"). We are on the brink of losing one of our most ancient and universal cultural values.

Unlike other forms of pollution, light pollution can be reversed. A simple act of switching off the lights when they are not in use can make a world of difference as far as reducing light pollution and saving energy. Zoning and curfew are two environmental approaches that are currently being practiced in many places around the world to regulate light pollution. Since light pollution is not the same everywhere, the Commission Internationale de l'Eclairage (CIE) has established a zoning system that divides places into environmental zones where specific requirements are recommended to limit obtrusive light at night for the types of activities take place in these zones. Curfew is a procedure in which lights are turned off at certain times during the dark hours and is often enforced by local legislation (Narisada and Schreuder 71-74). Installing light where and when it is needed, properly aiming the light beam to prevent it from emitting into the night sky, and using energy efficient lighting equipment and operation are all important factors that need to be considered when designing lighting in an outdoor setting (Watson, Plattus, and Shibley 7.10-3).

Whether the lighting is to provide visibility to perform certain tasks, accentuate certain features to enhance aesthetics in the landscape, or to make people feel safer walking and conducting other activities at night, the types of lighting applications need to be clearly defined in order to determine the light levels needed for the lighting design to be safe and effective (Narisada and Schreuder 508). Light level, also known as illuminance (in lux or footcandles), is a measure of the intensity of the incident light on a surface, per unit area; and is often measured using a light meter or by calculation. There are two types of illuminance: horizontal and vertical. Horizontal illuminance is the density of luminous flux falling onto a horizontal surface, such as a sidewalk. Vertical illuminance is the density of luminous flux falling onto a vertical surface, such as a statue (IESNA 10-5). The IESNA has established seven illuminance categories, “A” thru “G”; and organized them into three sets of visual tasks (see Table 2.1). According to the IESNA Exterior Lighting Design Guide (see Table 2.2), the illuminance recommended for outdoor applications generally falls into the categories “A” thru “C” with a few exceptions (10-13). Keep in mind that illuminance is only one of the many factors that needs to be considered in outdoor lighting design in order to achieve a comfortable, pleasant, healthy and safe nighttime environment (IESNA 21-2).

The severity of light pollution is not the same everywhere in the world; this means restrictive measures need to be applied accordingly to counteract the negative impact at a particular location. The Commission Internationale de l’Eclairage (CIE) has established a zoning system as shown in (Table 2.3), to form a base and serve as a frame of reference for lighting regulations. Zones are areas where certain activities take place and have distinctive characteristics to them whether natural or manmade (Narisada and Schreuder 71-72).

Table 2.1 Determination of illuminance categories* (IESNA 10-13)

	Categories	Visual Tasks	Recommended Illumination (lux)
Orientation and simple visual tasks. Visual performance is largely unimportant. These tasks are found in public spaces where reading and visual inspection are only occasionally performed. Higher levels are recommended for tasks where visual performance is occasionally important.	A	Public spaces	30 lx (3 fc)
	B	Simple orientation for short visits	50 lx (5 fc)
	C	Working spaces where simple visual tasks are performed	100 lx (10 fc)
Common visual tasks. Visual performance is important. These tasks are found in commercial, industrial and residential applications. Recommended illuminance levels differ because of the characteristics of the visual task being illuminated. Higher levels are recommended for visual tasks with critical elements of low contrast or small size.	D	Performance of visual tasks of high contrast and large size	300 lx (30 fc)
	E	Performance of visual tasks of high contrast and small size, or visual tasks of low contrast and large size	500 lx (50 fc)
	F	Performance of visual tasks of low contrast and small size	1000 lx (100 fc)
Special visual tasks. Visual performance is of critical importance. These tasks are very specialized, including those with very small or very low contrast critical elements. Recommended illuminance levels should be achieved with supplementary task lighting. Higher recommended levels are often achieved by moving the light source closer to the task.	G	Perform of visual tasks near threshold	3000 to 10,000 lx (300 to 1000 fc)
* To account for both uncertainty in photometric measurements and uncertainty in space reflections, measured illuminances should be with plus and minus 10% of the recommended value. It should be noted, however, that the final illuminance may deviate from these recommended values due to other lighting design criteria.			

Development and implementation of control measures to reduce sky glow, light trespass and glare through good lighting practice will work as the first line of defense again light pollution. The most important human-made sources that contribute to sky glow are light output and lamp related characteristics, light distribution from the luminaire, and reflected light from the ground surface (Light Pollution 8-9). Current methods that best control sky glow are (“Light Pollution” 8; IESNA RP-33-99 10):

1. Limit light near to and above the horizontal by using full cutoff luminaries. Applications Include lighting for streets, sports activities, parking lots and vehicle sales lots, etc.

Table 2.2 Exterior lighting design guide (IESNA Outdoor-1-6)

Outdoor Locations and Tasks	Illuminance (Horizontal) Category or Value (lux)	Illuminance (Vertical) Category or Value(lux)	Notes
Bikeways			
Alongside roadways - commercial areas	10	20	*
Distant from roadways	5	5	*
Building Exteriors			
Active Entrances	B	A	
Prominent structures	B	A	
Bulletin and Poster Boards			
Bright surroundings			
light surfaces	A	D	**
Dark surfaces	A	E	**
Dark surroundings			
Light surfaces	A	C	**
Dark surfaces	A	D	**
Flags, Floodlighted	C	A	
Gardens			
General lighting	5	2	
Paths, away from building	0	3	
Steps or ramps away from building	0	3	***
Background - fences, walls, trees, and shrubbery	20	5	
Flower beds, rock gardens	A	A	
Trees or shrubbery, emphasized	A	A	
Focal points, large	B	A	
Focal points, small	C	A	
Gazebos, trellises, decorative structures	B	A	
Terraces, patios, decks	B	A	***
Holiday and Entertainment			
Holiday and festival lighting	C	A	
Entertainment lighting	D	B	
Hospitality - Exterior			
Restaurants and dining areas	B	A	
Pool areas and terraces	B	A	
Parks, Plazas, and Pedestrian Malls	B	A	
Retail Spaces - Outdoor			
Fast food restaurants	C	A	
Car dealerships - business district			
Front row - adjacent to roadway	C	A	
Car dealerships - small towns			
Front row - adjacent to roadway	B	A	
Convenience stores	A	A	
Pedestrian mall	A	A	

2. Reduce light level to only what’s needed for certain night activities and tasks. Use the illuminance levels (see Table 2.2) established by IESNA as a lighting level guideline.

Table 2.2 Exterior lighting design guide continued (IESNA Outdoor-1-6)

Service Station			
Dark surroundings			
Approach	15	5	
Driveway	15	5	
Pump island area	A	A	
Building faces (exclusive of glass)	20	5	
Service areas	20	5	
Landscape highlights	10	3	
Light surrounding			
Approach	20	5	
Driveway	20	5	
Pump island area	B	A	
Building faces (exclusive of glass)	A	A	
Service areas	A	A	
Landscape highlights	20	5	
Sculptures	A	B	
Signs			
Advertising	A	C	**
Externally lighted roadway	A	C	**
Water and Rock Features			
Softscape (natural water bodies)	B	A	
Fountains, waterfalls	A	B	
Decorative pools	B	A	***
Large natural rock features	A	B	
Notes: * Intersections and conflict zones may require higher illuminances. ** Lighting must not interfere with visibility for pedestrians, motorists, or boaters. *** Hazards such as stairs or areas adjacent to bodies of water should be clearly identified and lighted for safety.			

Table 2.3 Environmental zone classification (IESNA RP-33-99 11-12)

Zone Rating	Surroundings	Lighting environment	Examples
E1	natural	intrinsically dark	national parks or protected area (where roads are usually unlit)
E2	rural	low district brightness	agricultural or residential rural areas
E3	suburban	medium district brightness	industrial or residential suburbs
E4	urban	high district brightness	town centers and commercial areas with high levels of nighttime activity

3. Turn off outdoor lighting when it’s not in use unless it’s necessary for safety and security purposes. Use lighting controls such as timer or motion sensor to turn on/off lights.

4. Minimize non-target illumination. Lighting systems that project light upward should be designed so that the light not illuminating the target area is minimized.

5. Limit lighting installations. More lighting installation means more potential light goes into the sky thus causes more sky glow.

6. Minimize reflected light from surfaces of objects and the ground by avoiding over-lighting; choosing construction materials that have lower reflection factor; and using manmade or natural structures such as shrubs to shield reflected light (Narisada and Schreuder 447-8).

7. Explore and choose luminaires that have good color rendition and light output, and are more energy efficient. They should be selected according to their application and compatible with site conditions. The various types of luminaires will be discussed more in detail in chapter 3.

In order to control the amount of light that goes directly into the sky, the Institution of Lighting Engineers (ILE) has suggested limits on the Upward Light Ratio (ULR) which represents the maximum permitted percentage of luminous flux for the total installation that goes directly into the sky for a specific environmental zone (3). (see Table 2.4)

Table 2.4 Upward Light Ratio (Institute of Lighting Engineers 3)

Environmental zone	**Sky glow ULR* (max %)**
E1	0
E2	2.5
E3	5
E4	15

* ULR is the Upward Light Ratio of the installation and is the maximum permitted percentage of luminaire flux for the total installation that goes directly into the sky.

Light trespass can be controlled following the suggestions made by the Illuminating Engineering Society of North America (IESNA). These suggestions include (IESNA RP-33-99 11):

1. Conduct a thorough site survey of the surrounding area during the lighting design to identify potential problems involving residences, roadways, and airports. Select luminaries, locations and perform proper installation that minimize light spill onto adjacent properties.

2. Use well-shielded luminaires and select luminaries that have intensity distribution control features, such as full cutoff reflectors and retractors.

3. Properly locate, mount and aim luminaires so that the light emitted will be contained within the designed area.

4. Keep floodlight aiming angles low so that the entire beam falls within the area where it is intended.

The Commission Internationale de l'Eclairage (CIE) has suggested illumiance limits to control light trespass, specified for different environmental zones (IESNA G-1-03 4). (see Table 2.5).

Table 2.5. Light trespass limits (Institute of Lighting Engineers 3)

Environmental zone	**Light into windows, vertical illuminance (lux)**	
	Before curfew	After curfew
E1	2	1*
E2	5	1
E3	10	2
E4	25	5
* Acceptable from public road lighting installations only		

Several outdoor luminaire cutoff classifications are defined and developed by the Illuminating Engineering Society of North America (IESNA) for glare control. The IESNA full cutoff, cutoff, and semicutoff designations limit the intensity of glare in the field of view. For these classifications, two relevant zones are defined with respect to the nadir of a luminaire (the nadir is defined as the angle that points directly downward, or 0˚ from the luminaire). One zone applies to angles that are between 80˚ and 90˚, including 80˚ and 90˚ above nadir, and the second zone includes all angles above the horizontal plane of the luminaire (See Figure 2.1.). Glare is more likely to be contributed by the light emitted in the 80˚ to 90˚ zone, and sky glow is contributed to the light emitted upward above the horizontal ("Light Pollution" 11-14). The IESNA cutoff classifications are (IESNA RP-33-99 17-19):

1. Full cutoff: A luminaire light distribution where luminous intensity (in candelas) at or above the horizontal plane of the luminaire is zero, and the luminous intensity at or above the 80˚ angle above nadir does not exceed 10% of the luminous flux (in lumens) of the lamp(s) in the luminaire.

2. Cutoff: A luminaire light distribution where luminous intensity at or above the horizontal plane of the luminaire does not exceed 2.5% of the luminous flux of the lamp in the luminaire, and the luminous intensity at or above an angle of 80˚ above nadir does not exceed 10% of the luminous flux of the lamp(s) in the luminaire.

3. Semicutoff: A luminaire light distribution where luminous intensity at or

above the horizontal plane of the luminaire does not exceed 5% of the luminous flux of the lamp in the luminaire, and the luminous intensity at or above an angle of 80˚ above nadir does not exceed 20% of the luminous flux of the lamp(s) in the luminaire.

4. Noncutoff: A luminaire light distribution where there is no luminous intensity limitation in the zone above maximum luminous intensity.

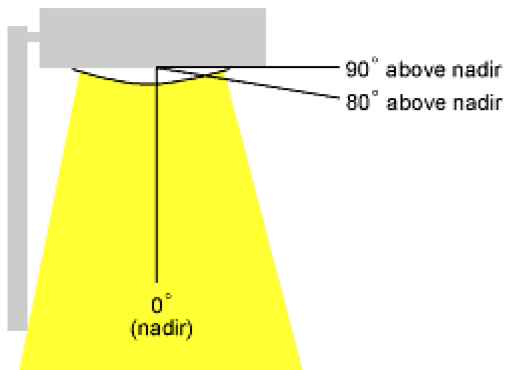


Figure 2.1 Angles reference by the IESNA cutoff classifications ("Light Pollution" 12)

Keep in mind that only the IESNA full cutoff classification does not emit any light directly up into the sky if installed correctly; the cutoff luminaire can emit light upward anywhere from 0-20% of the light output of the lamp(s) in the luminaire; and the value for the semicufoff luminaire can vary from 0-40% of the total lamp light output. It should also be noted that it is not always true that a cutoff luminaire emits less light upward than a semicutoff or even a noncutoff luminaire does. In 2007, the IESNA has adopted the Luminaire Classification System (LCS), a new system that can "provide more comprehensive data to evaluate the overall distribution of light from a luminaire" (IESNA TM-15-07 2). This new system supersedes the IESNA cutoff classifications (full cutoff, cutoff, semi-cutoff, and non-cutoff) and will be discussed more in detail in chapter 3 (IESNA TM-15-07 2). Since most outdoor lighting design requirements and criteria collected from the research materials used for this thesis are based on the IESNA luminaire cutoff classification system instead of the new Luminaire Classification Systems (LCS), there is a need to include both classification systems in this thesis.

Improper placing and aiming of floodlights can cause glare and light trespass. The Commission Internationale de l'Eclairage (CIE) has suggested using higher mounting heights when installing floodlights to prevent direct glare and light trespass onto neighboring properties ("Light Pollution" 10). The Institution of Lighting Engineers (ILE) has suggested to keep the main beam angle of all lights directed toward any potential observer to no more than 70˚, so that glare can be kept to a minimum (2).

The Institution of Lighting Engineers (ILE) has proposed limitations for glare specified in different environmental zones (see Table 2.6). The source intensity in the table applies to each source in the potentially obtrusive direction, outside of the area being lit. These limitations should be used to prevent glare from the site being lighted to its surroundings (The Institution of Lighting Engineers 3).

These light pollution control measures and lighting criteria should be considered and implemented for every outdoor lighting application. Light pollution won't go away unless we all make a conscious effort to enforce good lighting practice. It's also very important to raise public awareness of the negative impacts that light pollution could have on the natural environment, wildlife, culture, public health and safety; so that people will make informed decisions when selecting lighting equipment for their backyards, streets and communities, and form the habit of turning off the lights when they are not used.

Table 2.6 Limitations for glare (Institute of Lighting Engineers 3)

Environmental zone	**Source intensity (kilo candela)**	
	Before curfew	After curfew
E1	2.5	0
E2	7.5	0.5
E3	10	1
E4	25	2.5

<u>Crime Prevention Through Environmental Design (CPTED)</u>

The term Crime Prevention Through Environmental Design (CPTED) is defined by the National Crime Prevention Institute (NCPI) as "the proper design and effective use of the built environment can lead to a reduction in the fear and incidence of crime, and an improvement in the quality of life" (Crowe 46) CPTED is an environmental criminology theory, and its framework is based on multidisciplinary knowledge including the fields of architecture, urban design and planning, landscape architecture, sociology, psychology, anthropology, geography, human ecology, criminology and criminal justice (Atlas 53). It is crucial for the design professionals that are directly responsible for determining the design, planning, building and use of the physical environment to understand how to properly incorporate crime prevention into land use and design plans because the physical environment can either discourage or facilitate criminal activity and fear (Zelinka and Brennan 18).

There are three overarching principles in CPTED: natural access control, natural surveillance and territorial reinforcement. Natural access control includes using physical placements and designs of entrances, exits, signs, fencing, landscaping, and lighting as control measures to limit criminal accessibility and ensure early detection and observation of criminal intrusion and activity. Natural surveillance maximizes visibility of a space by organization of physical features, activities, and people in a way so that the normal users of the place are able to see and observe what's going on around them. The proper placement of windows, alignment of sidewalks and paths, locations and levels of lighting, types of vegetation used for planting design, and proper design and size of open spaces can all contribute to natural surveillance opportunities. Territorial reinforcement helps to establish a sense of ownership by clearly defining private spaces from semi-public and public spaces using physical attributes such as fences, walls, signage and landscaping. This sense of ownership can influence people to take responsibility and watch out for their own properties, neighborhood, community, and for each other (Zelinka and Brennan 21).

One of the main functions of outdoor lighting is to provide safety and security at night. Lighting for safety involves proper illumination of hazards that might put people in dangerous situations; for instance, tripping over a street curb, falling down steps, or in an extreme case, getting in a car accident. Hazards such as curbs, steps, sloped walkways, vehicle intersections, crosswalks, pedestrian path and any obstacle on a path must be properly illuminated (see Table 2.7) and made obvious to people to prevent accidents (Watson, Plattus, and Shibley 7.10-2; IESNA 29-16). Other than inadequate lighting level, there are many less tangible factors associated with poor lighting design that can also contribute to accidents, and they must not be overlooked. Some of these factors include glare, deep shadows and large differences in luminances. Luminance is "what an observer sees, whether it is the light reflected from a wall (surface luminance) or the light coming directly from a luminaire (luminaire luminance). Surface luminance and luminaire luminance both affect an observer's reaction to the outdoor environment" (IESNA RP-33-99 1). Both glare and deep shadows generated by over-lighting, poor aiming and uneven distribution of light can severely impair and obscure our vision at night, causing confusion, disorientation, accidents and fear. Excessive luminance differences between surfaces, areas and luminaires within the visual field can reduce our ability to see because our eyes have to readapt when alternately looking at areas of widely different brightness. It is important to establish a luminance ratio criteria for the site being lighted, and as a general rule, the luminance ratio should not exceed 20:1. This ratio should set the maximum luminance levels allowed between the site being lighted and its neighboring sites from which the site is viewed (IESNA 21-2-3).

Quality and effective lighting design not only makes the outdoor environment free of hazards for people to use at night, but also creates a perception of security and protects people and their properties from criminal activities. The Illuminating Engineering society of North America (IESNA) has summarized the general principles of security lighting as the following: to integrate lighting into the total security system thus effectively facilitating other security measures and procedures; to allow identification and observation of objects, people and places through illumination to eliminate possible hideout places; to deter criminal acts by creating a fear for identification, detection, and getting caught using illumination; to reduce the fear of crime for the general population by increasing the perception of security; and to use effective illumination that will allow early detection, avoidance and defensive actions to threats (IESNA G-1-03 2-5).

Table 2.7 Illumination level for safety (IESNA 29-2)

Hazards Requiring Visual Detection	**Slight**		**High**	
Normal Activity Level	Low	High	Low	High
Illuminance Levels				
Lux	5.4	11	22	54
Footcandles	0.5	1	2	5
Notes: These values represent absolute minimum illuminances at any time and location where safety is related to visibility. However, in some cases higher levels may be required (such as where security is a factor). In other conditions, especially involving work with light-sensitive materials such as photographic film, much lower illuminances must be used. In these cases, alternate methods of ensuring safety must be employed.				

Our common belief is that more and brighter lights increase the perception of security; however, to the contrary, results from many studies of crime rate and artificial lighting have shown otherwise. The City of Chicago conducted a two year study to evaluate what effect increased nighttime artificial illumination would have on crime rate in areas that were infested with high rate of crimes. The result was that reported crimes in the tested area actually increased in all categories 6 months into the testing period after the illumination level was increased ("Outdoor Lighting and Safety"). There also have been results from other studies showing a corresponding reduction in crime rates with increased lighting, and in some cases there was little or no change in crime level after lighting was increased. Even though most studies have shown mixed results of how lighting may affect crime, consistent findings from most studies were that people do feel safer and their fear of crime was lessened, as a result of improvement in outdoor lighting (Morrow and Hutton 19-20).

From the CPTED point of view, lighting, unlike what we have perceived, does not prevent or stop crime, however, it does give the users of the built environment the choice, freedom and time "to move forward, retreat back or stay put" (Atlas 383). Lighting can provide enough visual information and reaction time so that a potential attacker, intruder or a dangerous situation can be identified, recognized, detected, avoided and reported. Lighting can attract people and create more foot traffic and activities for a place at night, thereby making a place less prone to crime because an increase in the number of people in an area is a more effective deterrent of crime than an increase in light level (Watson, Plattus, and Shibley 7.10-2). Lighting can also attract bad activities and provide information for criminals to see their next victim (Atlas 383).

The CPTED goal of lighting is to use effective design to increase the perception of natural surveillance and security so that people would feel safe and comfortable being outside enjoying whatever legitimate activities they might at night; and by the same token, make criminals feel uncomfortable and vulnerable in their surroundings so that their opportunity and capability to carry out illegitimate acts is diminished (Atlas 384). The following design guidelines, criteria and strategies are highly recommended by the IESNA and CPTED professionals, and should be considered when designing lighting for various outdoor applications.

1. Use adequate and appropriate lighting level to maintain visual recognition of other users in a space. Lighting should be designed so that a person's face is able to be recognized from at least 30 feet away, and vertical illumination is essential to meet this design objective. Pedestrian walkways, sidewalks, access routes and other features in outdoor public spaces should be lit to the minimum standards of IESNA. (See Table 2.8) Alleys, secondary access routes, signage routes and signage should be properly lighted as well (Atlas 401; IESNA 21-5; IESNA G-1-03 3).

2. Make sure the distribution of illuminance is uniform, and luminance differences between surfaces or areas within the visual field is kept to a minimum to avoid glare, and high contrast between shadows and illuminated areas. Deep shadows can become potential hideouts for criminals to ambush or attack, and uncontrolled luminance differences can reduce visibility for people to see and detect threats thus increasing their chance of being victimized (Atlas 401). It is suggested that low mounting height with close spacing and a vertical illumination

pattern may be the most effective way to light pedestrian walkways if security is the primary concern (Watson, Plattus, and Shibley 7.10-2).

Table 2.8 Minimum illuminance level for security lighting (IESNA G-1-03 7-12)

Type of Space	Illuminance Horizontal Average (footcandles, fc)	Illuminance Vertical Average (footcandles, fc)	Uniformity Ratio (Average to Minimum)
Building facades		0.5-2 fc	8 to 1
Facial identification		0.5-0.8 fc (a)	4 to 1
ATM exterior	10 fc within 10 ft. 2 fc from 10-50 ft.	(a)	3 to 1 from 10-50 ft
Parking Garage for elderly (Entrance)	50 fc	(a), (i)	
Walkways around senior facilities	5 fc	(a), (l)	
Parking for public parks	3 fc	(a)	4 to 1
Trails, walkways	0.6 fc	(a), (j)	4 to 1
Supermarket, major retail parking	3 fc	(a)	4 to 1
Fast food restaurants parking	3 fc	(a)	3 to 1
Fast food restaurants drive up window out to 30ft	6 fc	(a)	3 to 1
Convenience stores/gas stations			
Pump areas	6 fc	(a)	4 to 1
Sidewalks and grounds	3 fc	(a)	4 to 1
Single family residence, exterior doorway		0.8 fc	
Multifamily residences common areas	3 fc	(a)	4 to 1
Multifamily residence mailbox areas	10 fc	(a)	4 to 1
Senior housing entrances (active hours)	30 fc	(a), (i)	
Senior housing entrances (sleeping hours)	10 fc	(a), (i)	
Schools and Institutions (general parking)	3 fc	(a), (l)	4 to 1
Schools sidewalks and footpaths	1 fc	(a), (l)	4 to 1
Hotels and motels; general parking	3 fc	(a)	4 to 1
Hotels and motels; sidewalks and grounds	1 fc	(a)	4 to 1

Notes: (a) Vertical illuminance of 0.5 to 0.8 fc or values that produce a uniformity ratio of no more than 4:1 (25% of horizontal illuminance). (i) See IESNA RP-28, Lighting and the Visual Environment for Senior Living. (j) Lighting should extend out on both sides of trail to a distance of 30 ft. (l) For special events, parking lots and grounds should be lighted 2 hours prior to 2 hours after the event. Source: Guidelines for Security Lighting for People, Property, and Public Spaces, IESNA, 2003

3. Position and aim light where it is needed; for example, lighting for sidewalks should shine on pedestrian pathways and possible entrapment spaces rather than on the main road where streetlights are already illuminating. Inset doorways, alcoves, and above or below grade entrances should be properly lighted to avoid criminals making these places for concealment (Atlas 401).

4. Use overlapping techniques to provide even coverage of lighting on a building façade and the immediate space around the building, preferably with a light beam aiming downward to prevent light going directly into the sky (Atlas 402).

5. Design lighting in coordination with street elements. Mature trees, vegetation and other street furnishings can block lighting systems. It is important to find out what elements do and will exist at the site, so that lighting can be designed accordingly to avoid blockage (Atlas 404).

6. Lighting should be designed to avoid nuisances, glare, and light trespass to the surrounding neighborhood. If security and crime prevention are major issues, then luminance ratio should be minimal (e.g. not to exceed 10:1) between the site being lighted and its neighboring sites. Minimizing light trespass might increase the chance for people to leave their blinds up at night, thereby giving the perception that someone may be watching out from the windows (Zelinka and Brennan 44-45; IESNA 21-3; 29-3).

7. Sometimes having no lighting is an effective crime prevention strategy. Many schools have adopted the practice of turning off all their lights except the emergency lights during non-use hours. It not only helped these schools to cut

down spending on electricity but also the number of vandalism incidents on school grounds (Atlas 407; “Light Pollution and Safety” 2).

8. Explore and choose luminaires that have good color rendition and light output, and are more energy efficient. Light sources rich in short wavelength (blue and green) light can increase peripheral vision, shortening a person’s detection and reaction time (IESNA RP-33-99 3-8). Lighting equipment should be selected according to their application and compatibility with site conditions (Atlas 388-96). The various types of luminaires will be discussed more in detail in chapter 3.

9. Light fixtures used must be able to resist vandalism especially in high crime areas. They should have unbreakable exterior, secure and vibration-free surface mounting and other protective features (Atlas 401).

10. Motion-sensor lighting can be used in places that are not supposed to be used at night. It helps to attract attention to suspicious activity, and at the same time save energy (Atlas 401).

There are many other factors that contribute to successful security lighting, including thorough site evaluation of high risk areas; facilitation of security personnel and Closed-circuit Television (CCTV) on site for certain areas that need additional security and protection; proper installation of emergency exit signs; collaboration with the law enforcement, and last but not least good maintenance of the lighting system (Atlas 397-413). Outdoor lighting alone cannot accomplish the task of making a place safe and creating a sense of good security; however, quality and effective lighting design is a tool that can be used in conjunction with all other CPTED considerations and design strategies to effectively and successfully accomplish this task.

Wayfinding

Have you ever been to an unfamiliar place and tried to find a store, a hotel, a restaurant, or a point of interest, either on foot or by a car, and there are no legible signs, no maps, or any other kind of visual information to help you to locate your destination even if you turn and follow the direction exactly as what your GPS tells you or do exactly what the stranger that seems to know exactly where it is, has told you; and you just cannot seem to find it? You drive or walk around in circles, trying to find out where it is by pulling over at the closest gas station to ask for directions, or asking the next stranger on the street to hopefully get a better answer; but are only left feeling more frustrated, confused, and stressed out. Is there a better way for people to find their way around in an unfamiliar place? The answer is yes. Effective wayfinding design will help people move through a space safely and efficiently without getting lost.

Wayfinding is how people get from one place to another, including the processes of information gathering and decision making; and is the “art and science of using signs, symbols, maps, and other two and three-dimensional informational, directional, and architectural elements to create a system to guide people to and through a place or destination” (Raphale 1). The planning, design, and implementation of wayfinding and public information systems involve the collaboration of landscape architect, architect, graphic designer, traffic engineer, and city planner (Raphale 1).

Elements in the built environment (i.e. cities or towns), such as paths, edges, districts, nodes and landmarks can help us understand the spatial structure, organization, connectivity and meaning of our surroundings. It is also very important to understand that our behavioral and cognitive abilities have direct effect on how we orient, and navigate through space (Raphale 2).

The three primary components of a wayfinding program must be considered and integrated into the design of effective wayfinding systems. These components are behavioral, functional and operational. The behavioral component focuses on understanding how people respond to their environment and to the actual signage and wayfinding cues, so the most effective signage and wayfinding elements can be produced and implemented. For example, the system must include audible communication and tactile elements to accommodate for users that are visually impaired. The functional component focuses on how the wayfinding system works with its setting or environment. The system must take into account Average Daily Traffic (ADT) and related volume, and provide assistance to different wayfinding needs. Important and memorable landmarks, buildings or landscapes can be used as functional elements to assist wayfinding. The operational component focuses on the processes of programming, policy making, implementation and maintenance of the wayfinding system (Raphale 7-9).

A successful wayfinding system is not only about making signs and where to place them, but also about integrating and organizing spatial elements, such as landmarks, landscape, architectural elements, lighting and other visual cues and elements in the environment. Universal design must also be incorporated into the wayfinding system to ensure accessibility to all people, regardless of their individual abilities and ages (Raphale 9-12).

Traveling from or going to places does not only happen during the day when there is plenty of natural light to show you the way. Ever since we have adopted the incessantly busy modern lifestyle and the invention of electricity, people can do a lot of the same things they do during the day at night. Imagine what it would be like getting lost at night when the visibility is low and there are not many places open or people around to ask for help. Careful outdoor lighting design can enhance the visual elements of a wayfinding system so that these elements are just as visible, recognizable, enjoyable, memorable and remarkable as they would be during the day. These visual elements include signs, landmarks, landscape, architectural elements, lighting and many other elements we experience in the built environment (Raphale 9).

Signage for directions, emergency exits, destinations should be illuminated to maximize clarity and legibility in the content of the messages. The following is a list of criteria for lighting signage:

1. Lighting for the signs should provide uniform lighting levels for the sign message; and should avoid glare or light spill beyond the sign surface. A maximum-to-minimum illuminance uniformity ratio of 6:1 and lower is

recommended for more legibility of the sign. Table 2.9 shows illuminances for externally lighted signs recommended by IESNA (22-24-5).

Table 2.9 Illuminance levels for signs (IESNA 22-25)

Ambient Light Level	Sign Illuminance		Sign Luminance* Candelas per square meter
	lux	footcandles	
Low	100-200	10-20 fc	22-44
Medium	200-400	20-40 fc	44-89
High	400-800	40-80 fc	89-178
* Based on maintained reflectance of 70 percent for white sign letters.			

2. External light sources, including spot lights, strip lights, neon, low-voltage, and solar powered fixtures, can be incorporated depending on the type of signage and location (Raphale 26).

3. Reflective vinyl lettering and graphics may be used in directional signing on roadways where there is ambient light from street lights or vehicle headlights (Raphale 26).

4. Shielded down-lighting using strip lighting design is recommended to prevent glare and light pollution. Internal illumination may be used as an option to comply with local regulations, and the light levels should be in accordance with local zoning ordinances (Raphale 26).

Landmarks that give places their identities are highly recognizable visual elements that are often points of destination and interest. People often use them as reference or decision-making points for directions and wayfinding. These elements can be in the forms of buildings, monuments, bridges, or other structures (Raphale 2). At night, proper lighting installation not only can define and enhance the appearance of these elements, but also can emphasize their importance as visual cues for wayfinding. The following recommendations should be considered when lighting these elements:

1. The techniques used to light structures include floodlighting, outlining, spotlighting, silhouetting, or any combination of these methods depending on what kind of effect is desired to be achieved. Lighting should be controllable in its direction, intensity and color to enhance architectural characteristics of the structure (IESNA RP-33-99 26).

2. Lighting only a few key architectural features or details of a structure can be quite effective in achieving desired results when using floodlights. This approach can also minimize light pollution. Low aiming angles, correct beam spread, appropriate illuminance levels (see Table 2.10.) and external and internal shielding should be incorporated to minimize light directed upward and spilled (IESNA RP-33-99 26-31).

Table 2.10 Illumiance level for floodlighting (IESNA 21-7)

Area Description	**Average Target Illuminance (vertical) (lux/footcandles)**
Bright Surroundings and Light Surfaces	50/5
Bright Surroundings and Medium Light Surfaces	70/7
Bright Surroundings and Medium Dark Surfaces	100/10
Bright Surroundings and Dark Surfaces	150/15
Dark Surroundings and Light Surfaces	20/2
Dark Surroundings and Medium Light Surfaces	30/3
Dark Surroundings and Medium Dark Surfaces	40/4
Dark Surroundings and Dark Surfaces	50/5

3. Highly reflective surfaces made of glass, marble, glazed tile or brick, and various metals should not be lighted directly; and the light source needs to

be treated in such a way so that it cannot be seen from normal viewing angles (IESNA RP-33-99 26).

Selected features in the landscape such as vegetation, fountains, sculptures, or other elements that are either manmade or natural can be properly illuminated to not only function as visual focal points for wayfinding at night, but also to create more enjoyable, beautiful and safe experiences for the night users.

1. Using appropriate lighting techniques, types of luminaire, and illumiance levels to light area that contains focal points, transition elements and background elements respectively to achieve desired effect with minimal glare and light spill (IESNA RP-33-99 31).

2. The foliage color and reflectance, and overall shape are all important factors to consider when lighting trees and other vegetation (IESNA RP-33-99 32).

3. The luminance ratios between the focal points and their surroundings should be somewhere between 5:1 and 10:1 (IESNA RP-33-99 32).

4. Lighting of natural features, such as waterfalls, streams, oceanfronts and others causes light pollution and disturbance to the natural environment and its wild inhabitants, and should be restricted to occasional special events. Oceanfront lighting is not recommended in areas near where sea turtles nest or near other areas that have sensitive marine biology (IESNA RP-33-99 32-3).

5. There are a few things that need to be considered when lighting fountains or other water features. It is important to determine the viewing geometry, the type of luminaire, and whether the water or the structure is to be

lighted. It is also important to understand how light is reflected, refracted and diffused when it interacts with water in order to properly locate and position the lighting equipment, as well as achieve the desired visual effect (IESNA RP-33-99 33-4).

6. Sculptures can be illuminated to reveal their shape or texture using different lamps, color filters, or beam patterns from different angles. Appropriate lighting techniques and shielded luminaires with correct beam spreads should be used to avoid uncomfortable glare (IESNA RP-33-99 31-4).

Roadways and streets connect all the elements together in the built environment, and should be designed into one complete system to accommodate for different modes of travel, and directing people from one place to another. Roadway and street lighting is the basic component of public lighting. Good lighting that provides quality visual information is critical to traffic safety and to the pedestrian's sense of direction and security at night. There are many different types of roadways, and they all have their own specific function and lighting requirements. It is very important to know the type of road (see Table 2.11) on which the lighting is going to be installed, as well as in which area (see Table 2.12) the road is adjacent to. The various paving materials used on the road surface have different surface reflectance characteristics which are crucial in the determination of pavement luminance (IESNA RP-33-99 36-8). The four types of road surface classification are as shown in Table 2.13. Two design criteria can be used as guidelines for continuous roadway lighting design depending on which one best addresses the needs of the projects (IESNA RP-8-00 7). These criteria are luminance and illuminance.

Table 2.11 Roadway classification (IESNA RP-33-99 37)

Roadway Classification	Description
Freeway	A divided major roadway with full control access and with no crossings at grade
Freeway Class A	Roadways with visual complexity and high traffic volumes, are usually found in major metropolitan areas in or near the central core and operates through much of the early evening hours of darkness at or near design capacity.
Freeway Class B	All other divided roadways with full control of access where lighting is needed.
Expressway	A divided major roadway for through traffic with partial control of access and generally with interchanges at major crossroads. Expressways for non-commercial traffic within park areas are generally known as parkways.
Major	The part of the roadway system that serves as the principal network for through traffic flow. The routes connect areas of principal traffic generation and important rural highways entering the city.
Collector	The roadways serving traffic between major and local roadways. These are road ways used mainly for traffic movements within residential, commercial, and industrial areas.
Local	Roadways used primarily for direct access to residential, commercial, industrial, or other abutting property. They do not include roadways carrying through traffic. Long local roadways will generally be divided into short sections by a system of collector roadway systems.
Alley	Narrow public ways within a block, generally used for vehicular access to the rear of abutting properties.
Sidewalk	Paved or otherwise improved areas for pedestrian use, located within public street rights-of-way which also contain roadways for vehicular traffic.
Pedestrian Walkway	A public walk for pedestrian traffic, not necessarily within the right-of-way for a vehicular traffic roadway. Included are skywalks (pedestrian overpasses), subwalks (pedestrian tunnels), walkways giving access to parks or block interiors, and midblock street crossings.
Bikeway	Any road, street, path, or way that is specifically designated as being open to bicycle travel, regardless of whether such facilities are designed for the exclusive use of bicycles or are to be shared.

1. Luminance criteria. In the luminance method of roadway lighting design, the amount of light reflected from the pavement in the direction of the driver is used to determine how “bright” the road is. Pavement luminance level and uniformity ratio (see Table 2.14) are recommended for different road and

area classifications. Veiling luminance ratios must also be determined to avoid disability glare from the fixed lighting system (IESNA RP-8-00 7).

2. Illuminance criteria. In the illuminance method of roadway lighting design, the amount of light incident on the roadway surface from the fixed lighting system is determined. Average maintained illuminance values (see Table 2.15) are recommended for various road and area classifications depending on the type of pavement used. Specific limits are also set for Illuminance uniformity and veiling luminance ratios for different classifications (IESNA RP-8-00 7).

3. Choose appropriate luminaires, mounting heights and lateral luminaire positions to meet the recommended luminance or illuminance level, uniformity, and veiling luminance control. Luminaire supports (pole and bracket) selected should adhere to good traffic safety practice; be aesthetically acceptable in appearance; and have minimal operation and maintenance costs (IESNA 22-2-12; IESNA RP-33-99 38-9).

4. No separate lighting system is required for walkways and bikeways that can receive adequate lighting from the roadway lighting system. Additional lighting may be required for walkways that don’t get adequate lighting from adjacent roadways. The recommended horizontal and vertical illumiance levels for pedestrian ways are as shown in Table 2.16. Walkways do not have to be lighted continuously if they have minimal non-pedestrian traffic, or are located in the middle of a park or large landscape area. A unique blend of lighting that covers key landscape features, selected buildings or shelters, resting points and hazards along the walkway, needs to be attained so that pedestrians would have

enough visual cues to know where hazards or important destinations are located. Use "human scale" lighting elements to create more depth and details for pedestrian's sense of space and security. Disability and uncomfortable glare, and harsh shadows should be avoided in the design (IESNA RP-33-99 38-9).

Most outdoor lighting we experience at night is monotonous with the same lighting levels, fixtures, sources and color scheme. Such lighting does not define a space or give character to a neighborhood or community during the day and at night. Good outdoor lighting combined with the rest of wayfinding design elements and strategies will be able to create a sense of order for any place, and provide a successful wayfinding system that caters to all users.

Table 2.12 Area classification (IESNA RP-33-99 38)

Area Classification	**Description**
Commercial	A business area of a municipality where ordinarily there are many pedestrians during some of the night hours. This definition applies to densely developed business areas outside, as well as within, the central part of a municipality. The area contains land use which frequently attracts a heavy volume of night time vehicular and pedestrian traffic.
Intermediate	Those areas of a municipality characterized by frequent, moderately-heavy night time pedestrian activity. This definition applies to blocks having libraries, community recreation centers, large apartment buildings, industrial buildings, or neighborhood retail stores.
Residential	A residential development, or a mixture of residential and small commercial establishments, characterized by few pedestrians at night. This definition includes areas with single-family homes, town houses, and small apartment buildings.

Table 2.13 Road classification (IESNA 22-2)

Class	Description	Mode of Reflectance
R1	Portland cement, concrete road surface. Asphalt road surface with a minimum of 15 percent of the aggregates composed of artificial brightener and aggregates	Mostly diffuse
R2	Asphalt road surface with an aggregate composed of a minimum 60 percent gravel (size greater than 10 millimeters). Asphalt road surface with 10 to 15 percent artificial brightener in aggregate mix. (Not normally used in North America).	Mixed (diffuse and specular)
R3	Asphalt road surface (regular and carpet seal) with dark aggregates (e.g., trap rock, blast furnace slag); rough texture after some months of use (typical highways).	Slightly specular
R4	Asphalt road surface with very smooth texture.	Mostly specular

Table 2.14 Luminance method (IESNA 22-10)

Road and Area Classification		Average Luminance Lavg	Luminance Uniformity Lavg/Lmin (maximum allowed)	Luminance Uniformity Lmax/Lmin (maximum allowed)	Veiling Luminance Ratio Lvmax/Lavg (maximum allowed)
Freeway Class A		0.6	3.5	6	0.3
Freeway Class B		0.4	3.5	6	0.3
Expressway	Commercial	1	3	5	0.3
	Intermediate	0.8	3	5	
	Residential	0.6	3.5	6	
Major	Commercial	1.2	3	5	0.3
	Intermediate	0.9	3	5	
	Residential	0.6	3.5	6	
Collector	Commercial	0.8	3	5	0.4
	Intermediate	0.6	3.5	6	
	Residential	0.4	4	8	
Local	Commercial	0.6	6	10	0.4
	Intermediate	0.5	6	10	
	Residential	0.3	6	10	

Notes: (1). Lv = veiling luminance (2). These tables do not apply to high mast interchange lighting systems, e.g., mounting heights over 20 meters (3). The relationship between individual and respective luminance and illuminance values is derived from general conditions for dry paving and straight road sections. This relationship does not apply to averages. (4). For divided highways, where the lighting on one roadway may differ from that on the other, calculations should be made on each roadway independently. (5). For freeways, the recommended values apply to both mainline and ramp roadways. * For approximate values in candelas per square foot, multiply by 0.1.

Table 2.15 Illuminance method (IESNA 22-10)

Road and Area Classification		Pavement Classification R1 (lux)	R2 and R3 (lux)	R4 (lux)	Illuminance Uniformity Ratio Eavg/Emin	Veiling Luminance Ratio Lvmax/Lavg (maximum allowed)
Freeway Class A		6	9	8	3	0.3
Freeway Class B		4	6	5	3	0.3
Expressway	Commercial	10	14	13	3	0.3
	Intermediate	8	12	10		
	Residential	6	9	8		
Major	Commercial	12	17	15	3	0.3
	Intermediate	9	13	11		
	Residential	6	9	8		
Collector	Commercial	8	12	10	4	0.4
	Intermediate	6	9	8		
	Residential	4	6	5		
Local	Commercial	6	9	8	6	0.4
	Intermediate	5	7	6		
	Residential	3	4	4		

Notes: (1). Lv = veiling luminance (2). These tables do not apply to high mast interchange lighting systems, e.g., mounting heights over 20 meters (3). The relationship between individual and respective luminance and illuminance values is derived from general conditions for dry paving and straight road sections. This relationship does not apply to averages. (4). For divided highways, where the lighting on one roadway may differ from that on the other, calculations should be made on each roadway independently. (5). For freeways, the recommended values apply to both mainline and ramp roadways. ** For approximate values in footcandles, multiply by 0.1.

Table 2.16 Illuminance level for pedestrian ways (IESNA 22-11)

Walkways and Bikeway Classification	**Minimum Average Horizontal Levels (Eavg) in (lux)**	**Average Vertical Levels For Special Pedestrian Security (Eavg)** in (lux)***
Sidewalks (roadside) and Type A bikeways:		
Commercial areas	10	22
Intermediate areas	6	11
Residential areas	2	5
Walkways distant form roadways and bikeways:		Type B
Walkways, bikeways, and stairways	5	5
Pedestrian tunnels	43	54

Notes: * Crosswalks traversing roadways in the middle of long blocks and at street intersections should be provided with additional illumination. ** For pedestrian identification at a distance. Values at 6 feet above walkway. *** For approximate values in footcandles, multiply by 0.1.

Synthesis of Lighting Requirements and Recommendations

After a close investigation of the issues of outdoor lighting directly linked to light pollution, CPTED and wayfinding, it is clear that the design criteria and requirements that are being addressed in the areas of light pollution and CPTED have covered a wide range of similar lighting issues, such as lighting level, lighting technique, luminaire and lamp selection, luminance ratio, uniformity ratio and lighting control. It is interesting to see that poor lighting design that contributes to light pollution can also contribute to an unsafe condition and the increase in fear of crime. The issues of outdoor lighting linked to wayfinding did not directly address the lighting design in terms of lighting levels, techniques, and luminaire selections, etc, with the exception of signage illumination. However, the importance of outdoor lighting as a visual element that can enhance wayfinding design was emphasized. Lighting design, in the case of wayfinding, is really about where and what needs to be lighted in the built environment. The findings from the investigation have been reviewed and synthesized as the following:

- Determine what needs to be lighted: Lighting certain elements in the built environment can prevent hazardous situations, reduce fear of crime, enhance wayfinding, and create a more pleasant visual or emotional experience. These elements include but are not limited to:

  - Hazards
  - Signage and signage routes
  - Certain landmarks

- Selected features in the landscape

- Roadways and intersections that have high volume of vehicular and pedestrian traffic

- Pedestrian walkways, sidewalks, access routes, alleys, secondary access routes that do not receive adequate lighting from roadway lighting

- Possible concealment and entrapment areas

● Determine appropriate lighting level: Use just the right amount of illuminance, including both horizontal and vertical to provide visibility for a specific application or task; the detection of a hazard or threat; and wayfinding. It will also prevent unnecessary over-lighting which directly contributes to light pollution. The following tables can be used as guidelines for a specific application (If the values in these tables appear to be different for the same application, use the more restricted value.):

- Table 2.2 shows illuminance levels recommended for various outdoor applications, and Table 2.1 shows the classification of illuminance categories.

- Table 2.8 shows illuminance levels recommended for security lighting and - Table 2.7 shows illuminance levels for hazards.

- Table 2.5 shows illuminance limits to control light trespass specified for different environmental zones.

- Table 2.16 shows minimum illuminance levels for walkways and bikeways.

- Table 2.9 shows illuminance levels for signs.

- Table 2.10 shows illuminance levels for floodlighting buildings and monuments.

- Table 2.15 shows illuminance values for roadway lighting design using the illuminance method.

- Table 2.4 shows the maximum permitted percentage of luminous flux for the total installation that goes directly into the sky for a specific zone.

● Proper lighting technique: It depends on what needs to be lighted; for instance, the technique used to light a fountain is quite different from what is used to light a building façade. Proper lighting technique not only can achieve desired visual effect, but also can help prevent all forms of light pollution. Lighting technique includes the following:

- Aiming angle and positioning of the light source,

- Mounting height, and the location and spacing of luminaires,

- Viewing geometry.

● Determine appropriate lighting fixture and source: Lighting equipment should be selected according to their application and compatibility with site conditions (IESNA 21-6). They should posses the following qualities:

- Good color rendition and light output,

- Energy efficiency,

- Good Shielding with intensity distribution control features, such as full cutoff reflectors and retractors,

- Interesting color filters and various beam spreads that can create special visual effects,

- Visually appealing, adding aesthetics and definition to a space,

- Resistance to vandalism,

- Ease of maintenance.

● Luminance ratio: This is defined by the IESNA as the "ratio between the luminances of any two areas in the visual field" (G-21). This ratio should be kept to a minimum to avoid creating glare and deep shadows that can severely impair and obscure our vision at night, causing discomfort, confusion, disorientation, accidents and fear; as well as disruption of the theme in a community (IESNA 21-2-3). The luminance ratio criteria are recommended for the following applications:

- 20:1 as a general rule, in a community setting,

- Not to exceed 10:1 for security and crime prevention,

- Should fall between 5:1 and 10:1 between the focal points and their surroundings when lighting the landscape.

● Luminance and illuminance uniformity ratios: These ratios are crucial to determine appropriate luminance and illuminance levels for continuous roadway lighting design. The following criteria can be used for these applications:

- Table 2.15 for roadway lighting design using the illuminance method,

- Table 2.14 for roadway lighting design using the luminance method,

- A maximum-to-minimum illuminance uniformity ratio of 6:1 or lower is recommended for more legibility of the signage.

- Consideration of the existing elements at a site and its surroundings: Conduct a thorough survey of the site and its surrounding area to identify potential glare and light trespass to adjacent properties. Existing elements on site, such as street furnishing, and mature trees can block the lighting. Other elements and criteria to consider including:

  - Choosing construction materials that have lower reflection factor to minimize reflected light from surfaces of objects and the ground,

  - Incorporating manmade or natural structures to shield reflected light,

  - Selecting limitations for glare in different environmental zones, (Table 2.6)

  - Selecting limits to control light trespass for different environmental zones. (Table 2.5)

- Lighting control: Turn off outdoor lighting when it is not in use by physically switching off the light or using a timer or motion sensor to turn on/off lights.

These design criteria and strategies should be considered and integrated into the lighting design process for outdoor applications that involve activities and nighttime users. They address the lighting issues that are directly linked to light pollution, CPTED and wayfindng.

CHAPTER 3

LIGHTING SOURCES AND TECHNOLOGY

A Brief History of Lighting

From the most primitive methods of making fire to the most advanced lighting technologies that we know today, the development of artificial lighting has come a long way. The first candles were made of animal fat and plant fibers contained in hollowed-out stone as a source for illumination, and were used by ancient Egyptians around 3000 BC. Oil lamps were then created by ancient Greeks and Romans using bronze or pottery that burned vegetable oils. These lamps were quite popular during the Middle Ages until the invention of oil-wick lamps which provided a brighter burn by allowing air to reach the flame. The Argand lamp and kerosene lamp were widely used back in those days. Gas lamps replaced the oil-wick lamps in the 1800s and became popular as street lights; these were replaced by electric lamps after their invention in the late 1800s and early 1900s. It was not until the independent development of the incandescent lamp by Sir Joseph Swan in England and Thomas Edison in the United States, that electric lights became popular. The number of available light sources on the market has increased significantly since the introduction of the first incandescent lamp. In addition to improvements in the Edison lamp, mercury vapor lamps were introduced in the 1930s, followed closely by the introduction of fluorescent lamps in 1939. Tungsten-halogen lamps were introduced in the 1950s; and in the subsequent decade, metal halide and high pressure sodium lamps came on the market. The introduction of other light sources such as electrodeless lamps and then LED lamps has brought the development of light sources into a new chapter (IESNA 6-1). The quality of these available light sources will continue to improve over the coming years. It will be just a matter of time before the emergence of more sophisticated and cutting-edge lighting technologies.

Energy Efficient Lighting Sources

In the United States, since most of the electricity is generated by burning fossil fuels, decreasing the amount we consume can reduce a significant amount of CO2 emission produced during power generation (Howard, Brinsky, and Leitman, 2-4). It is estimated that the total amount of CO2 can be reduced by up to 50 percent in 20 years in the United States if a complete conversion to energy efficient lighting takes place. Energy efficient lighting in the simplest terms is defined as “to reduce the amount of time a bulb is on or reduce the amount of electricity the bulb consumes” (Howard, Brinsky, and Leitman, 17-21) The rest of this chapter will explore energy efficient light sources and technology by first reviewing conventional lamps and luminaires that have been widely adopted for outdoor lighting; then looking into LED, the most advanced and energy efficient light source available, and solar lighting, a technology that converts the energy of the sun into electricity for lighting without relying on the electrical grid (Howard, Brinsky, and Leitman 90, 173).

Choosing the right kind of lighting source can be quite challenging especially with the variety of light sources that are available. What makes one lamp a better choice than another? When choosing light sources for specific applications in the outdoor environment, color rendering index, correlated color temperature and spectral power distribution of the light source are very important to determine how the light will affect the color of the objects, as well as our mood within the lighted area. Efficacy and lamp lumen depreciation of the light source are equally important because they can determine the efficiency and lifespan of the lamp (IESNA RP-33-99 16).

Color rendering index "measures the light source's ability to render colors accurately" (Howard, Brinsky, and Leitman 28). The higher the color rendering index of the light source, the more accurate the true color of the object would appear under the light. If color rendering is the key factor in the design, then a light source with high color rendering index should be considered. The correlated color temperature can be thought of as heating a piece of metal, and the color of the metal changes gradually from different shades of red to different shades of white as the temperature of the metal increases. The color temperature of a light source is the temperature (measured in Kelvin) at which the metal is heated to a color that most resembles the color of the light source. Thus the warmer (red) the light appears to be, the lower the correlated color temperature, and the cooler (white) the light, the higher the temperature. Cooler lights in the 4000 K to 5000 K range can be used when lighting green plant materials in the landscape. Warm light in the 2100 K to 3500 K range can be used for a warmer setting where activity is taking place. Spectral power distribution "shows the relative amounts of power at wavelengths of different colors". For example, if a light source is weak in green wavelength output, the leaves on a shrub may appear dull under this source at night (IESNA RP-33-99 16).

Efficacy of the light source, measured in lumens per watt, is the ratio between the light output emitted to the total electric power consumed by the source. The higher the number, the more efficient the light source will be, and vise versa (Howard, Brinsky, and Leitman 25). Lamp lumen Depreciation (LLD) is "the decrease in lumen output that occurs as a lamp is operated, until failure" (IESNA G-20).

Let's first take a look at the most common light sources and luminaires on the market. These light sources include incandescent, fluorescent, high-intensity discharge (HID), and low-pressure sodium lamps.

Incandescent lamps create light by running electricity through a metal filament wire until it reaches a very high temperature that makes the wire glow (Howard, Brinsky, and Leitman 34). The average operating life for a typical incandescent lamp is about 1000 hours. They are the most common type of lighting used because of their excellent color rendition and low cost; however, they are extremely energy inefficient because only 5% of input power is converted into visible light and the rest is lost as wasted heat (International

Energy Agency 110-111). The three common types of incandescent lamps are standard incandescent, tungsten halogen and reflector lamps. Tungsten halogen lamps are 30 percent more efficient than standard incandescent, and they also have a longer life span. Reflector lamps are mainly used for floodlighting, downlighting and spotlighting (Howard, Brinsky, and Leitman 37-43).

A fluorescent lamp is a low-pressure discharge lamp that uses electricity to excite the mercury vapor that is in the glass tube. The excited mercury vapor then produces ultraviolet radiation that in turn activates the phosphor lining the glass tube, producing visible light. Fluorescent lamps are much more efficient and can last much longer than incandescent lamps (International Energy Agency 115). There are two common types of fluorescent lamps: fluorescent tubes and compact fluorescent lamps (CFL). Fluorescent tubes have been mostly used in commercial or institutional buildings due to their high efficiency, longer operating time and easy maintenance. They usually come in linear or sometimes U shapes, and are named by the diameter of the tube (Howard, Brinsky, and Leitman 55-59). Compact fluorescent lamps are designed to replace the regular incandescent lamp because they use one-quarter to one-fifth as much energy to produce the same light output as incandescents and they can last 5 to13 times longer than incandescent lamps (International Energy Agency 120-122). Even though the initial cost of a compact fluorescent lamp is four times more expensive than an incandescent lamp, a significant amount of electricity cost can be saved over the lifespan of a compact fluorescent lamp (Howard, Brinsky, and Leitman 64).

High-intensity discharge lamp (HID) creates light by forming an arc of electricity between two electrodes that are sealed in a tube filled with a mercury, sodium, or metal halide gas as the conductor (International Energy Agency 125). They are commonly used for outdoor lighting and large indoor spaces. The most common types of high-intensity discharge lamps include mercury vapor, high-pressure sodium and metal halide lamps. Mercury vapor lamps are the oldest type of HID and have been primarily used for security and street lighting (Howard, Brinsky, and Leitman 45), but due to their energy inefficiencies and lumen output depreciation characteristics, are discouraged for outdoor area lighting (IESNA RP-33-99 16). High-pressure sodium lamps are the most efficient of all HID lamps and are becoming the most common type of lamp for outdoor lighting. Metal halide lamps are less efficient than high-pressure sodium lamps but they have the best color rendition among HID lamp types (Howard, Brinsky, and Leitman 46). They are now available in various sizes and configurations for both commercial and residential applications.

Low-pressure sodium lamps produce light when the solid sodium filled inside the glass gas-discharge tube is heated and vaporizes (Howard, Brinsky, and Leitman 43). They are the most efficient electrically-powered lighting sources available and can last for a long time, but their color rendition is very poor and they often cast a monochromatic bright yellow light (International Energy Agency 124-125). They have been widely used for outdoor applications such as street lighting and security lighting (Howard, Brinsky, and Leitman 43).

Some basic information, as shown in Table 3.1, is provided for several different lamps that are commonly used for safety and security lighting in terms of color rendering index, correlated color temperature, spectral power distribution effects and efficiency. Table 3.2 is a more comprehensive review of various lamps by comparing their efficacy, color rendition, color temperature and life span. Both tables can be used as guide when selecting lamp types. As you can see from the review, overall, incandescent lamps are the least energy efficient, but have the best color rendition; the low pressure sodium lamps are the most energy efficient, but with the worst color rendition; and the HID lamps are just as efficient as fluorescent lamps, with the exception of mercury vapor lamps, but their color rendition is poor compared to fluorescent lamps, with the exception of metal halide lamps. It really all comes down to selecting light sources that can provide the best quality lighting, and are the most suitable for the application as well as energy efficient.

Luminaire is another crucial element in outdoor lighting design because it directly affects the installation, operation, maintenance and quality of the lighting system. Outdoor luminaires, according to the IESNA, are classified by “the manner in which they are mounted, by the intensity distribution they exhibit, by the degree to which they provide cutoff, and, if floodlights, by their beam patterns” (IESNA 21-7). Compatible ballast should be selected for HID and fluorescent lamps to ensure proper operation of the fixture and the lamp (IESNA RP-33-99 16).

Table 3.1 Comparison of various sources (IESNA G-1-03 17)

Light Source	CCT* (K)	CRI**	Spectral Power Distribution Effects		Efficacy (LPW) (1)	LLD (2)	Life (hours)	Starting and Warmup Times (minutes) (3)	Dimming Range (% light output)
			Colors Enhanced	Colors Dulled					
Standard Incandescent	2700	100	red, orange, yellow	blue, green	17	85	750	0	100-0
Tungsten Halogen (reflector)	2850	100	red, orange, yellow	blue, green	14	95	2500	0	100-0
Fluorescent (halophosphate phosphors)	3000 - 4100	62	yellow, blue, orange	red	82	85	20,000	0	100-0
Fluorescent (rare earth phosphors)	2700-5000	72-90	all	none	89	85	20,000	0	100-0
Mercury Vapor	5700	15	blue, red	green	45	60	24,000	<10	100-0
Metal Halide	3000 - 6000	65-90	blue, green, yellow	red	90	80	20,000	<10	100-50
High Pressure Sodium	1800 - 2200	22	yellow	red, blue	104	90	24,000	<5	100-50
Low Pressure Sodium	1800	-44	yellow	all but yellow	126		18,000	<10	na

(See manufacturers' catalogs for specific data. Notes: * Correlated Color Temperature in Kelvin. ** Color Rendering Index. (1). Efficacy for lamp is shown in lumens per watt. Ballasting is required for all lamps except standard incandescent and tungsten halogen. (2). Lamp Lumen Depreciation as defined in the IESNA Lighting Handbook for each light source. (3). Time intervals to reach usable light output.

Table 3.2 Light sources comparison chart
Source:http://www.energysavers.gov/

Lighting Comparison Chart

Lighting Type	Efficacy (lumens/watt)	Lifetime (hours)	Color Rendition Index (CRI)	Color Temperature (K)	Indoors/ Outdoors
Incandescent					
Standard "A" bulb	10–17	750–2500	98–100 (excellent)	2700–2800 (warm)	Indoors/ outdoors
Tunsgen halogen	12–22	2000–4000	98–100 (excellent)	2900–3200 (warm to neutral)	Indoors/ outdoors
Reflector	12–19	2000–3000	98–100 (excellent)	2800 (warm)	Indoors/ outdoors
Fluorescent					
Straight tube	30–110	7000–24,000	50–90 (fair to good)	2700–6500 (warm to cold)	Indoors/ outdoors
Compact fluorescent lamp (CFL)	50–70	10,000	65–88 (good)	2700–6500 (warm to cold)	Indoors/ outdoors
Circle	40–50	12,000			Indoors
High-Intensity Discharge					
Mercury vapor	25–60	16,000–24,000	50 (poor to fair)	3200–7000 (warm to cold)	Outdoors
Metal Halide	70–115	5000–20,000	70 (fair)	3700 (cold)	Indoors/ outdoors
High-pressure sodium	50–140	16,000–24,000	25 (poor)	2100 (warm)	Outdoors
Low-Pressure Sodium	60–150	12,000–18,000	-44 (very poor)		Outdoors

The IESNA has classified luminaires into several different types based on how far their effective major light output is reached on a ground plane (IESNA 22-2-7). These luminaire configurations are shown in Figure 3.1. A brief description for each type is given in Table 3.3. Selecting the best light distribution types for lighting a particular roadway or an area can help to address the concerns for light pollution, uniformity, visibility and cost.

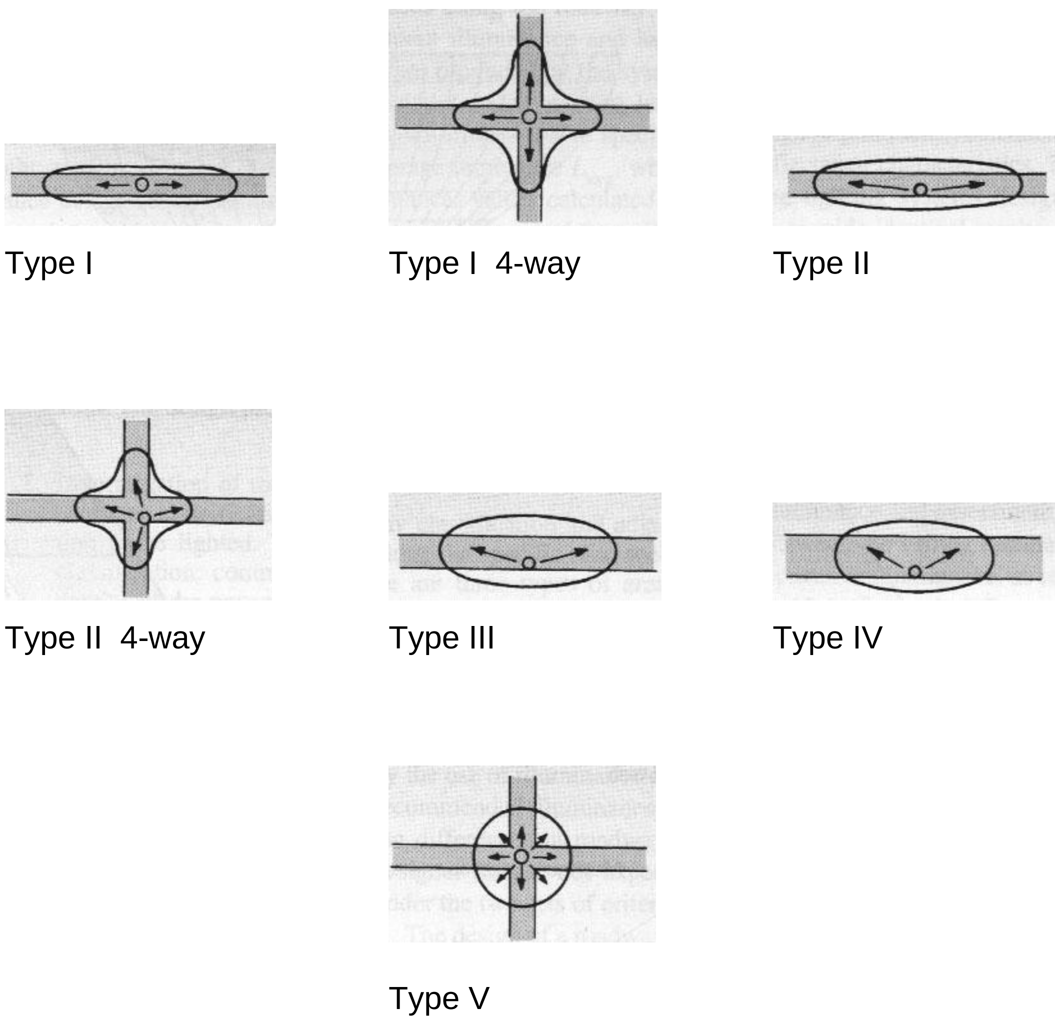
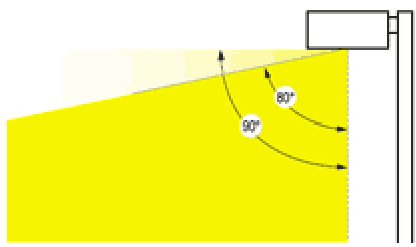


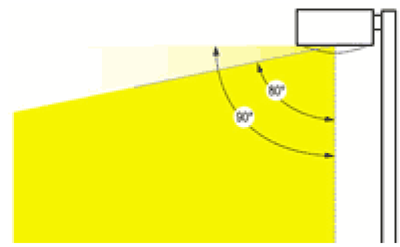
Figure 3.1 The IESNA light distribution classification for seven different luminaire configurations used to provide coverage for roadways (Type III), parking lots (Type III and V), and pedestrian areas (Type II, III, and V) (IESNA RP-33-99 6)

Table 3.3 Description of illuminance distribution (IESNA 7-8)

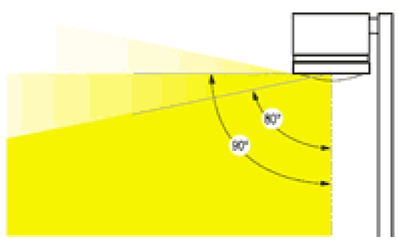
Name	Description of illuminance distribution
Type I	Narrow, symmetric illuminance pattern
Type II	Slightly wider illluminance pattern than Type I
Type III	Wide illuminance pattern
Type IV	Widest illuminance pattern
Type V	Symmetrical circular illuminance pattern



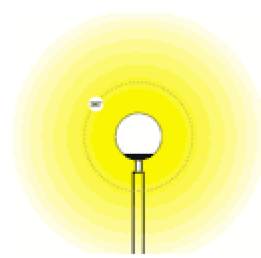
Full Cutoff



Cutoff



Semicutoff



Noncutoff

Figure 3.2 IESNA Luminaire Cutoff Classification
Source: http://www.schreder.us/uplight-darksky.html

There are four cutoff classifications for outdoor luminaires: full cutoff, cutoff, semicutoff and noncutoff (see Figure 3.2) as discussed earlier in chapter 2. However, the IESNA outdoor luminaire cutoff classification system is now superseded by the new IESNA Luminaire Classification System (IESNA TM-15-07 2). The new Luminaire Classification System (LCS) defines the distribution of light from a luminaire within three primary solid angles (see Figure 3.3) which are defined as forward light, back light and uplight (IESNA TM-15-07 2).

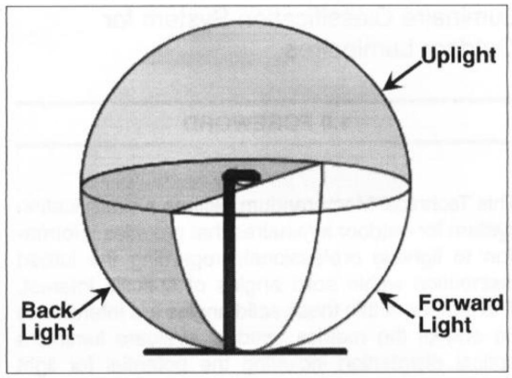


Figure 3.3 The three primary solid angles of the Luminaire Classification System (LCS) (IESNA TM-15-07 2)

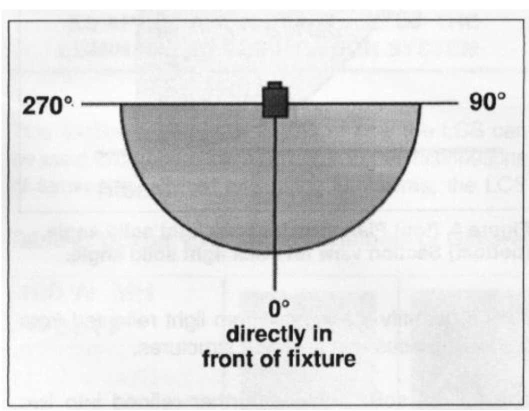
Forward light depicts the light distributed in front of the luminaire. It measures the quantity of light distributed close to the pole and at a further distance from the pole, in solid angles; and provides the ability to evaluate the potential for glare. The forward light solid angle is defined between 270 to 90 degrees (see Figure 3.4) horizontally in front of the luminaire, and between 0 and 90 degrees vertically. The forward light solid angle is further divided into four vertical secondary solid angles (see Figure 3.4). These secondary angles are defined as the following ((IESNA TM-15-07 3):

1. Forward light low secondary solid angle (FL): Light emitted between 0 and 30 degrees vertically, and from directly below the luminaire to 0.6 mounting heights away from luminaire.

2. Forward light mid secondary solid angle (FM): Light emitted between 30 and 60 degrees vertically, and from 0.6 to 1.7 mounting heights away from the luminaire.

3. Forward light high secondary solid angle (FH): Light emitted between 60 and 80 degrees vertically, and from 1.7 to 5.7 mounting heights away from the luminaire.

4. Forward light very high secondary solid angle (FVH): Light emitted between 80 and 90 degrees vertically, and beyond 5.7 mounting heights away from the luminaire.



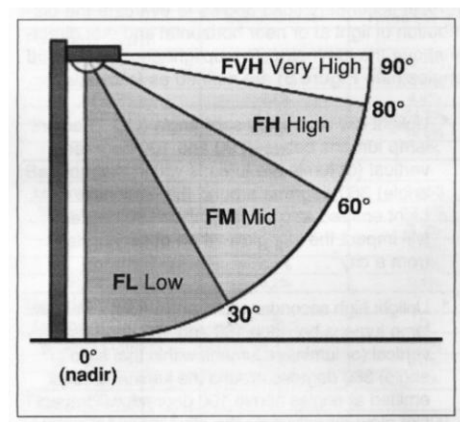


Figure 3.4 (left) Plan view for forward solid angle, (right) Section view for forward solid angle (IESNA TM-15-07 3)

Back light depicts the light distributed behind the luminaire. It provides the ability to evaluate the potential for light trespass when luminaires are located near the property line by measuring the quantity of light distributed close to the pole and at a further distance from the pole, in solid angles. The back light solid angle is defined between 270 to 90 degrees (see Figure 3.5) horizontally in back of the luminaire, and between 0 and 90 degrees vertically. The back light solid angle is further divided into four vertical secondary solid angles (see Figure 3.5). These secondary angles are defined as the following ((IESNA TM-15-07 4):

1. Back light low secondary solid angle (BL): Light emitted between 0 and 30 degrees vertically behind the luminaire, and from directly below the luminaire to 0.6 mounting heights away from luminaire .

2. Back light mid secondary solid angle (BM): Light emitted between 30 and 60 degrees vertically behind the luminaire, and from 0.6 to 1.7 mounting heights away from the luminaire.

3. Back light high secondary solid angle (BH): Light emitted between 60 and 80 degrees vertically behind the luminaire, and from 1.7 to 5.7 mounting heights away from the luminaire.

4. Back light very high secondary solid angle (BVH): Light emitted between 80 and 90 degrees vertically behind the luminaire, and beyond 5.7 mounting heights away from the luminaire.

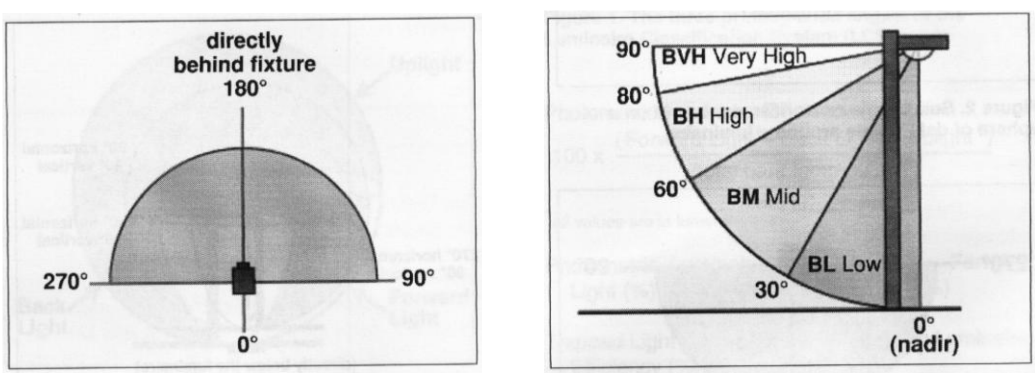


Figure 3.5 (left) Plan view for back light solid angle, (right) Section view for back light solid angle (IESNA TM-15-07 4)

Uplight depicts the light distributed above the luminaire. It measures the quantity of light at or near horizontal in a solid angle to provide the ability for evaluating potential upward light emission that contributes to sky glow. The uplight solid angle is defined between 0 to 360 degrees (see Figure 3.6) horizontally around the entire luminaire, and between 90 and 180 degrees vertically. The uplight solid angle is further divided into two vertical secondary solid angles (see Figure 3.6). These secondary angles are defined as the following ((IESNA TM-15-07 4):

1. Uplight low secondary solid angle (UL): Light emitted between 90 and 100 degrees vertically 360 degrees around the luminaire. Light within this angle will impact the sky glow when observing far from a city.

2. Uplight high secondary solid angle (UH): Light emitted between 100 and 180 degrees vertically 360 degrees around the luminaire. Light within this angle will impact sky glow directly over the city.

This new Luminaire Classification System should be used in conjunction with the luminaire light distribution types (Type I through V) when selecting the luminaire type for the application.

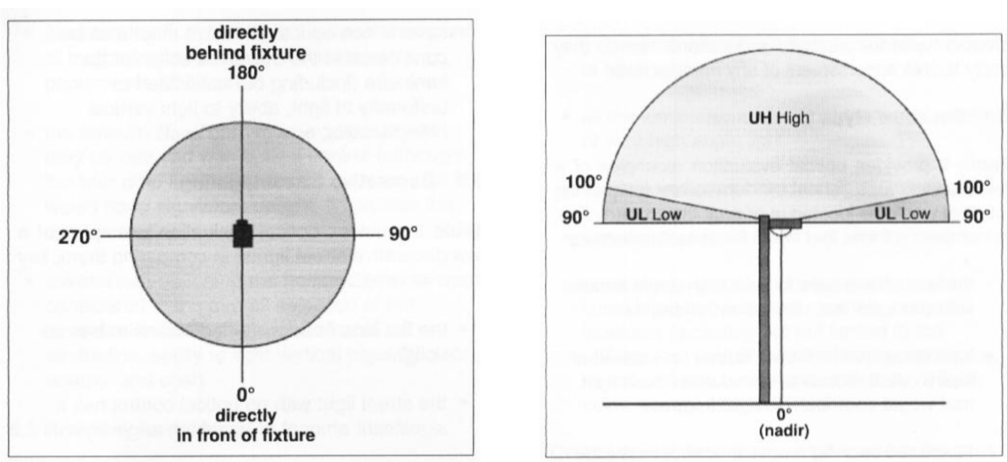


Figure 3.6 (left) Plan view for uplight solid angle, (right) Section view for uplight solid angle (IESNA TM-15-07 5)

Luminaires are also classified as three general types by the way how they are mounted. There are pole-mounted, surface-mounted, and bollard luminaires. Pole-mounted luminaires are often used for roadway and parking lot lighting. Typical luminaires used for vehicular roadways, also known as cobra-head luminaires, often have a dropped-dish refractor and are mounted on brackets off a vertical support pole. These luminaires produce wide light intensity distributions, and can cause excessive brightness, glare and upward light emission. Use of cutoff luminaires with flat lenses for better optical control is recommended as an alternative. Cutoff luminaires mounted on short arms with either flat-bottomed or clear dropped lenses are often used for lighting parking lots. They can be arranged in single, twin, or quad configurations to provide symmetric or asymmetric distributions. Small luminaires mounted on short poles are often used for lighting pedestrian walkways and grounds. Surface-mounted luminaires are mounted on walls or ceilings of a structure and are often used to provide lighting for a parking structure or walkways adjacent to a building. Bollard luminaires are often used for localized lighting for walkways and other pedestrian areas because of their small size; however they should not be used as the only source of illumination because they cannot illuminate higher vertical surfaces, such as faces (IESNA 21-6-7).

Floodlight luminaires are often used for building façades, sports lighting, and other special applications. Depending on the angular size of the object being illuminated and the distance to the mounting location, a wide range of intensity distributions (from narrow to very broad) are used to achieve the desired effect. For example, narrow beams are required for column lighting, accent lighting and distant mounting locations. Floodlights should have external or internal glare shields to prevent light spill and upward light emission (IESNA 21-7). Selecting the most suitable luminaires in terms of their light distribution pattern, cutoff classification, mounting type, and adaptability to the environment not only will provide the best lighting control and prevent light pollution, but also can save energy and maintenance costs.

Light Emitting Diode (LED)

Now let's take a look at LED lighting technology. Light-emitting diodes (LEDs) are made with treated semi-conducting materials that can produce light when electricity flows through them. The diodes are often enclosed in tiny lenses or encapsulants. Because the light output from an individual LED is small compared to a traditional lamp, multiple diodes are often used together to produce more light. The color emitted by LEDs varies depending on the materials used to make the diodes. White light is created by mixing light from red, green and blue LEDs or by coating a blue or ultraviolet LED with phosphor (Howard, Brinsky, and Leitman 91-95).

The underlying technology of LED lighting can be traced back to 1907 when it was first been discovered by a British researcher named Henry Round. It was Nick Holonyak of General Electric, who invented the first visible LED in 1962. The first generation LEDs were very expensive and were only used as indicator lights for laboratory equipment, and soon after that, many consumer electronics, such as calculators, TVs, and radios etc. started adopting the use of LEDs. Different colors of LEDs were then developed with the invention of bright blue LEDs in the 1990s by a Japanese scientist, Shuji Nakamura. This major breakthrough had made the creation of bright white LEDs for lighting possible (Howard, Brinsky, and Leitman 91-93).

LED technology is relatively new for lighting and there is still much room for improvement, such as their relatively expensive price and color rendering ability. Comparing to traditional lamps, LED lamps (see Table 3.4) use 90 to 95 percent less energy than incandescent lamps and they can last 10 to 20 years on average and provide tens of thousands of hours of light. They are very durable and can withstand vibration and extreme conditions. They can produce different colors more efficiently and be used for a wide-range of applications. They can achieve instant full brightness, and do not contain toxic mercury (Howard, Brinsky, and Leitman 91).

Table 3.4 General characteristics of LED lamps
Source:http://www.energysavers.gov/

Lighting Type	Efficacy (lumens/watt)	Lifetime (hours)	Color Rendition Index (CRI)	Color Temperature (K)	Indoors/ Outdoors
Cool White LEDs	60–92	35,000–50,000	70–90 (fair to good)	5000 (cold)	Indoors/ outdoors
Warm White LEDs	27–54	35,000–50,000	70–90 (fair to good)	3300 (neutral)	Indoors/ outdoors

LED has been gradually gaining ground for general lighting for a wide-range of applications in recent years. Some of these applications include interior accent and task lighting, elevator lighting, step and path lighting, retail display cases, traffic signals, signs and outdoor area lighting. LEDs for lighting outdoor areas such as roadways, parking lots and pedestrian areas can have many advantages over traditional metal halide and high-pressure sodium sources in terms of efficiency, uniformity and lifespan. Well-designed LED outdoor lamps can provide required illuminance using less energy, more precise cutoff of backlight and uplight, and more uniform distribution of light across the target area. LED lamps may last much longer (50,000 hours or more, compare to 15,000 to 35,000 hours) with better lumen maintenance. According to the Department of Energy, outdoor area lighting appears to be a promising application for LED technology. Careful information gathering and research of new LED products are recommended to ensure high quality performance and economic payback ("Overview of Outdoor Area Lighting").

Solar Lighting

Solar lighting systems use solar cells, also known as photovoltaic (PV), that convert sunlight directly into electricity. The electricity generated is stored in batteries for use at night for lighting homes as well as outdoor areas. Solar cells are the basic building blocks of a PV system and are typically interconnected to form panels or modules for more power production. The material making up the cells and the energy of the sunlight being absorbed are two key factors of determining how efficient the system is in converting solar energy into electricity. There are a variety of solar cell materials available with varying conversion efficiency, and the most popular types are silicon based. The intensity and amount of sunlight absorbed by a PV system depends largely on the geographic location, time of the day and time of the year. For example, there is more solar energy at noon on a clear summer day in Denver, CO than in the early morning of a winter day in Seattle, WA. PV systems should be installed and oriented accordingly to maximize the amount of daily and seasonal sunlight that they receive at specific geographic locations. These systems can be connected to an existing electric grid system or they can stand alone depending on the application and preference (“Outdoor Solar Lighting”). Some advantages of PV systems include: sunlight is directly converted into electricity, there are no mechanical moving parts and noise involved, they can last for a very long time, the energy source from the sun is free and inexhaustible, and there is no pollution (Goetzberger and Hoffmann 2).

The development of primitive solar cells started as early as 1839 and the first efficient solar cell was made in 1954. In the following decade, solar cells were primarily used on satellites and spacecraft. After the oil crisis in the early 1970s, the solar cell industry started development of cheap solar cells for land use to respond to the urgent search for alternatives to oil. In the 1990s, the international concern for global warming, a negative consequence of the use of fossil fuels to supply the world’s energy, has grown rapidly and further accelerated the development of photovoltaics (Green 22-29). The development and manufacture of PV system have advanced significantly in recent years due to the growing demand for renewable energy sources. As of 2010, solar photovoltaic generates electricity in more than 100 countries and is the fastest growing power-generation technology in the world (“Renewables 2010 Global Status Report” 19).

Solar outdoor lights are becoming increasingly common because, other than free electricity, they are safer and easier to install than traditional lighting, which often involves running power lines or underground wiring and ducting. Solar lighting systems can be self-contained units (see Figure 3.3), or the solar panel may be separate from the light fixture (see Figure 3.4). Types of solar outdoor lights can range in size and function from small, colorful, decorative garden lights (see Figures 3.5 and 3.6) to pole-mounted lights for parking lots and roadways (see Figures 3.7 and Fig 3.8). These lights are becoming increasingly available in hardware and lighting stores, (e.g. Lowe’s and the Home Depot for small landscape solar lights) as well as many online stores. (e.g. solarlightingusa.com and solarone.net for pole-mounted roadway or parking lot lights) The solar panels must receive the manufacturer’s recommended hours of sunlight in order for the solar lights to produce the desired amount of light at night (Howard, Brinsky, and Leitman 178-179).

Selection of lamps and luminaires for specific applications has to be based on the lighting requirements, the design intent and criteria, the budget and the physical location of the site. An energy efficient lighting system that saves energy, but doesn’t meet lighting requirement and design criteria is still a bad design. A landscape lighting installation with all LED lamps might work wonderfully for some customers, but not necessarily for others who have a limited budget. A solar powered roadway lighting system might work perfectly year-round in New Mexico, but not in Alaska during the winter. LED lamps and solar lights are certainly great alternatives to traditional lamps, but if they are not feasible for every situation, for whatever reason, then there is still a very large selection of traditional lighting equipment that can also provide high quality lighting with energy efficiency. It's always good to look at all viable options before making the final selection.

Figure 3.7 (Image to the left) Self-contained solar power system
Source: http://www.solarone.net/applications/GalleryS1CAurora.cfm

Figure 3.8 (Image to the right) Bollard lighting with separate solar panel
Source: http://www.solarone.net/applications/GalleryGardcoBoll.cfm

Figure 3.9 (Image to the left) Moonlight solar lanterns

Source: http://www.gardenbasket.com/moonlight_colors.html

Figure 3.10 (Image to the right) Solar yard lights

Source: http://www.landscapelighting1.com/tag/focus-landscape-lighting/

Figure 3.11 Solar roadway lights

Source: http://www.solarone.net/applications/gallerylosmasdar.cfm

Figure 3.12 Solar parking lot lights

Source: http://www.solarone.net/applications/GalleryLPBAppleby.cfm

CHAPTER 4

CASE STUDIES

Introduction

This chapter will describe four outdoor lighting design case studies. Due to limited accessibility of technical information, the information presented for each case study only reflects what is available during the research. The project from each case study takes place in a different context within the built environment, and has its own uniqueness and quality in design. General design effects and their relationships with other aspects of the sites will be emphasized. Three of these lighting designs have been recognized and awarded either by the International Association of Lighting Designers (IALD) or the Illuminating Engineering Society (IES). These lighting designs are chosen because they are excellent examples of what outdoor lighting design can achieve in terms of minimizing light pollution, while at the same time meeting lighting requirements for wayfinding and CPTED. The lighting design in each case study is successfully integrated into the total design of the site, complementing other design elements and maximizing the functionality of the space for its intended purpose.

The Citygarden

Citygarden (see Figure 4.1) is a sculpture garden located in the heart of downtown St. Louis, Missouri. As part of the city's downtown revitalization plan, Citygarden has been a huge success on many levels since its opening in 2009. Citygarden is designed by Nelson Byrd Woltz Landscape Architects in collaboration with the architectural firm, Studio Durham, and two lighting design firms. The garden not only features two dozen contemporary sculptures by world renowned artists, but also landscape elements that signify the history, natural beauty and characteristics of the local region through the use of water, limestone and native vegetation. Throughout the day, visitors from all walks of life and age groups come to the garden to contemplate, to see the sculptures, to play in the water, to eat, and to simply just have a good time ("Citygarden").

Figure 4.1 Citygarden during the day

Source: http://www.rbldi.com

At night, the garden is just as lively and spectacular as it is during the day once the light comes on. Accent lighting is added to all sculptures, three water features, the arc wall, walking paths and selected plants. Designed by Fisher Marantz Stone and Randy Burkett Lighting Design, the lighting design in the garden is fun, interactive, visually pleasant, and in many ways what a quality outdoor lighting design should be. The following is an excerpt from an online article by Enlighter Magazine:

"Two firms collaborated to meet the demands of the project; one firm tending to lighting the landscape, hardscape and waterscape to embrace the botanical theme and the other to create a visually striking, yet contextually sensitive, presentation of the art; while ensuring a secure urban nighttime experience".

The 24 pieces of sculptures that are displayed outside in the garden are made of different materials ranging from metals to stones, and vary considerably in design, size and shape. These sculptures are not only for viewing, but also for active engagement (e.g. climbing and touching, etc.). Lighting equipment for most of these sculptures (see Figure 4.2 and Figure 4.3) is embedded in the ground with appropriate aiming angles so that the light cast upward only highlights the target areas on the sculptures, enhancing their unique shapes, textures and artistic expressions. The use of this type of lighting is also safe for visitors to engage with these sculptures at night without being in physical contact with the lighting equipment. The lighting for each sculpture achieves the overall desired visual effect and blends seamlessly with the rest of the elements in the garden.

Figure 4.2 “2 Arcs x 4, 230.5 Degree Arc x 5” by Bernar Venet
Source: http://www.enlightermagazine.com/projects

Figure 4.3 “Tai-Chi Single Whip” by Ju Ming
Source: http://www.rbldi.com

The arc wall, a 550 foot long wall which runs diagonally through the garden, is constructed of limestone. The arc wall is lighted with similar techniques used for lighting the sculptures. Luminaires and light sources are embedded in the limestone pavement that is adjacent to the bluestone paved path along the wall (see Figure 4.4), providing an even “wash” of light on the wall. The light bouncing off the wall also provides sufficient visibility for the adjacent pedestrian path (see Figure 4.4). The walkway is directly illuminated only where there is no incidental source light already present (see Figure 4.5). There is no widely broadcast light, as that would ‘flatten’ shapes and textures, and conceal spatial shapes.

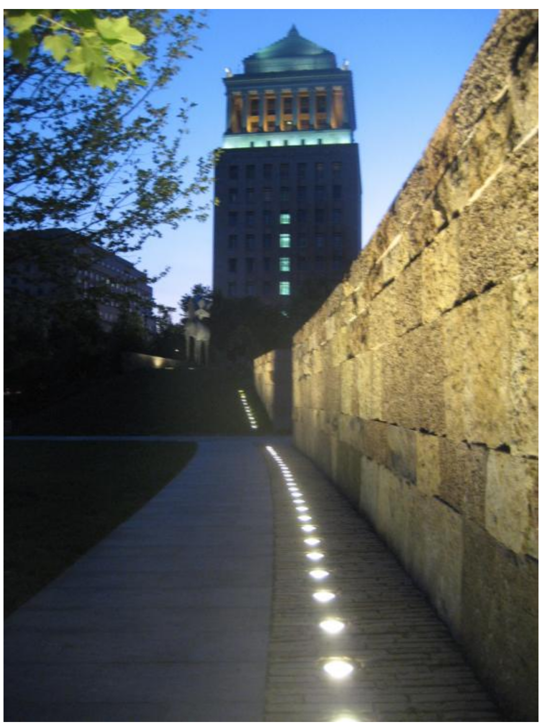


Figure 4.4 (Image to the left) Walking Path along the Limestone Wall
Source: http://urbanreviewstl.com

Figure 4.5 (Image to the right) Main Walking Path along the Central Axis of the Garden with the Gateway Arch in the far distance
Source: http://www.enlightermagazine.com/projects

One of the water features, the interactive spray plaza (see Figure 4.6), consisting of 102 vertical water jets that can shoot water as high as six feet in the air, is one of the main attractions to many children and adults alike. Each water jet is housed in a stainless steel canister that also serves as a water drain. Two LED lights are incorporated into each unit and protected by an acrylic lid. At night, the LED lights from each water jet are activated and illuminate the shooting water with a rainbow of colors that are exuberant and inviting ("Citygarden a Splashing Civic Success").

Figure 4.6 The Spray Plaza at Night
Source: http://www.rbldi.com

Instead of the typical post top luminaires, most luminaires used for the lighting design in Citygarden are embedded either in the ground or the pavement, and are appropriate and effective. Bollard luminaires are also used in some areas in the garden to illuminate path and vegetations. Selected landscape elements are accentuated with appropriate lighting techniques, equipment and amount of light, complementing one another and the rest of the landscape. The overall lighting in the garden is warm, inviting, interesting and harmonious.

The High Line

The High Line is a linear and elevated urban park (see Figure 4.7) which extends over nine city blocks, crossing a significant historical district and residential neighborhood on the West Side of Manhattan in New York City. What is so unique about this park is that it has re-used an abandoned railroad, turning it into a contemporary green space that "redefines the New York experience, affording never-before seen views of the city's surrounding natural landscape as well as an expansive and intimate look into one of the world's most dynamic urban environments" (Fehrenbacher 1). Elevated 30 feet above the ground, with meandering pathways, comfortable sitting arrangements and a primarily native, resilient, and low-maintenance landscape, the High Line is not only a place to escape from the hustling and bustling city down below, but also a habitat for animals, insects and birds. It has attracted millions of visitors since its opening in 2009 and has become one of the most trafficked public spaces in New York City ("The High Line, Section 1").

Figure 4.7 The High Line during the day
Source: http://www.asla.org/2010awards/173.html

The lighting for the High Line is designed by L'Observatoire International. At night, energy efficient LED lights gently illuminate the pathways, benches and plantings at waist level or lower, allowing eyes to adjust to the ambient light of the surrounding city sky (Cilento). The lights are embedded underneath the guardrails and benches (see Figure 4.8 and 4.9), creating a safe and comfortable nighttime environment without obtrusive and excessive lighting. "You make the entrances bright and as people's eyes adjust they see farther into the city. You light the floor and that is it. It is peaceful, not intrusive. Less artificial light is better" (Sheftell 2) says lighting designer Descottes in an interview with New York Daily News. At the Chelsea Market Tunnel (see Figure 4.10 and 4.11), one section on the High Line, a combination of blue and white LED fixtures are installed on the ceiling of the tunnel, creating a dramatic space at night overlooking the Hudson River ("The High Line, Section 1").

Figure 4.8 Lights are embedded underneath the benches

Source: http://www.asla.org/2010awards/173.html

Figure 4.9 Lighted pathway and plants

Source: http://www.lobsintl.com

Figure 4.10 The Chelsea Market Tunnel

Source: http://www.lobsintl.com

Figure 4.11 A close up view of the Chelsea Market Tunnel

Source: http://www.asla.org/2010awards/173.html

Large-scale overhead pole lighting is not used and only three types of light sources are used in the entire park (Sheftell 2). The lighting design for the High Line is simple but sophisticated and effective. LED lights are ideal for lighting this park because of their durable and energy saving nature. The lighting level, technique and equipment used preserve the views of the city nightscape and the dark sky beyond, minimizing light pollution and encouraging nighttime activities.

Queen's Walk

Queen's Walk on London's South Bank between the OXO Tower and the National Theatre was re-lighted by Speirs and Major Associates, a UK lighting design firm. Darkness preservation was one of the key concepts in this project. The original cast-iron lamps for lighting the walkway along the river edge (see Figure 4.12) were refurbished to retain their historical character, maximize their efficiency, and minimize light spill into the river. The original strings of tungsten festoon lighting hung between the lamp posts were taken off and replaced with 400 LED lights (75% white and 25% blue) in the adjacent 37 mature trees that line the walkway (see Figure 4.13). The large public open space adjacent to the walkway was intentionally left in complete darkness (see Figure 4.14), except for the trees and benches ("Lure of the Dark Side"). This design strategy not only enhances the view of the river and the City of London beyond, but also protects the local bio-diversity. The post top lamps along the river edge provide sufficient lighting for the walkway. The soft blue light cast from the LED lights in the trees almost resembles bright moonlight. The combination of the lights forms "an almost magical quality in which the degree of darkness helps to enhance the overall project rather than detract from it" ("Lure of the Dark Side").

Figure 4.12 The lamps and lighted walkway along the river
Source: http://www.speirsandmajor.com

Figure 4.13 Blue and white LED lights in the adjacent trees
Source: http://www.speirsandmajor.com

One of the major concerns for this project was pedestrian safety due to the prominent location of the site and the level of darkness used for the overall re-lighting of the site. Nevertheless, this project was well received by the public and the lighting of Queens Walk has become “a model not only for the rest of that stretch of the river but also for how the retention of darkness has an important role to play in public lighting” (“Project Queen’s Walk, South Bank”).

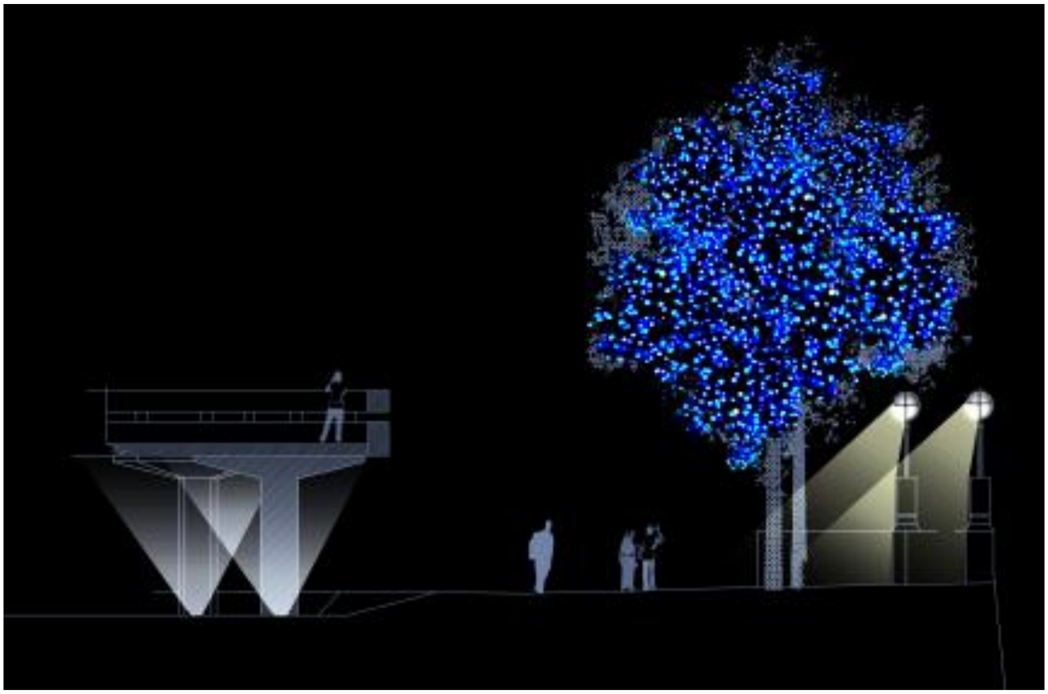


Figure 4.14 Section view of the Queen's Walk lighting concept
Source: http://www.speirsandmajor.com

Plaza del Torico

Plaza del Torico is the main square of Teruel, the capital city of the Teruel Province in Northeastern Spain. Teruel is a small city, but with a wealth of medieval history and architecture. It earned a World Heritage site designation in 1986. The city of Teruel also embraced the idea of modernism and innovation while planning for the renovation of its several important sites, including Plaza del Torico. The rehabilitation of Plaza del Torico included the paving and lighting systems as well as the overall aesthetic (Renzi).

Re-lighting for the plaza was designed by a collaboration of b720 Arquitectos, an architectural firm and Artec 3, a lighting design firm, both based in Spain. The plaza has an irregular and triangular shape, and "is completely surrounded by a portico beneath which are numerous shops" (Bordas). The Torico Fountain is located on one end of the plaza. Underneath the plaza, there are two underground cisterns which were once used to collect rain water for drinking, but are now opened to the public as exhibits to show their historic legacy, archaeological and educational value.

Figure 4.15 Lighting on the ground surface and building façades
Source: http://www.archdaily.com

A total of 1,230 LED lighting strips with glass casing (see Figure 4.15) are embedded into the surface of the plaza which is paved with basalt slabs. "The lighting strips traced on the dark basalt paving are a scattering of luminous segments that, by means of varying their orientation and density of grouping, reproduce the square's patterns of water drainage. The pattern thus translates the lines of flow of the rainwater and the curves, bifurcations and eddies it generates on meeting with obstacles on the surface (e.g. the fountain) and below the ground (the two cisterns) (Bordas). The graphic pattern of the lighting strips signifies what is below and its historic significance. The color schemes (see Figure 4.16) and intensity of the lighting strips are adjustable through a central computer.

To accentuate their elegance and minimize light pollution, the façade and porches of the surrounding buildings are evenly illuminated with a linear and low-voltage LED lighting system (see Figure 4.15) that has replaced the old lamp posts. A false ceiling (see Figure 4.17) has been built in the portico surrounding the plaza to conceal any visible cables and wires, and is also lighted with a soft band of recessed lighting (Renzi).

The lighting of the facades and porches is not overpowering and does not compete but complements with the lighting at the surface level of the plaza. The lighting strips are a visual representation of the town's identity and heritage. They are not only functional as part of a lighting system but also very much an intrinsic design element that connects all the pieces together. The innovative lighting design for Plaza del Torico gives this town a contemporary feel without compromising its historical integrity. The lighting not only provides a beautiful and safe nighttime environment, but also helps to tell the visitors a story about the past, the present and the future of the city Teruel.

Figure 4.16 Red color lighting scheme at the plaza

Source: http://archporn.wordpress.com

Figure 4.17 Lighting of the false ceiling in the portico

Source: http://architecturelab.net

CHAPTER 5

EAST CAMPUS VILLAGE DESIGN APPLICATION

Introduction

Located on the east side of UGA campus, the East Campus Village (ECV) is a community of four apartment-style residence halls that houses more than 1,200 students (see Figure 5.1). These residence halls include Vandiver Hall, McWhorter Hall, Rooker Hall and Building 1512 ("East Campus Village"). In this chapter, the outdoor lighting in one section within the East Campus Village is chosen to be reviewed for its advantages and disadvantages in terms of light pollution problems, wayfinding and CPTED needs. Other issues that might directly and indirectly affect the quality of lighting at this site will be reviewed as well. Based on the findings from the review, three design alternatives will be proposed to address these lighting issues. The graphic representations used for these designs are not technically accurate and are more conceptual and suggestive in nature. The designing and building of East Campus Village were completed more than eight years ago by multiple collaborating architectural, engineering and construction firms. A search was made for ECV's original lighting concept drawings and specific lighting designer's name at UGA's Physical Plant and in contacts with other known designers, but they were not found. In an interview, the university's housing director was able to discuss his current general philosophy of exterior lighting, but not specific considerations for ECV's original design. Therefore the analysis of the ECV's existing outdoor lighting design is based on my firsthand observation and interpretation of the existing lighting. The advantage of purely firsthand observation of installed lighting is that it focuses on actual lighting effects in the complex three-dimensional space, and rather than a designer's or manager's theoretical concerns or agendas.

The section chosen for review (see Figure 5.2) includes the front entrance and courtyard of Vandiver Hall, the pedestrian path that is adjacent to McWhorter Hall and the courtyard of Vandiver Hall, and the circular open space that connects the east entrance to building 1512. Unlike the main entrance location of other residence halls where a fair amount of illumination is provided from the nearby street lights along the vehicular and pedestrian paths, the front entrance and courtyard of Vandiver Hall are in a somewhat enclosed area where lighting could pose an unique design challenge. Other than being used by the residents of Vandiver Hall, the pedestrian path located between McWhorter and the courtyard of Vandiver has a fair amount of traffic when students from other apartments cut through here to get to their point of interests. The circular open space situated in the center of the quad is visually perceived as the central gathering space where many outdoor activities may take place. Several metal benches for sitting are provided in this area. The underpass of Building 1512 connecting the circular open space is where many residents from other buildings walk to get to and from the Ramsey Student Center, the parking deck and the dining facility and shops of the East Village Commons, etc. Although the chosen section cannot represent the entire East Campus Village outdoor area, it is a good representation on a smaller scale of what constitutes the ECV landscape.

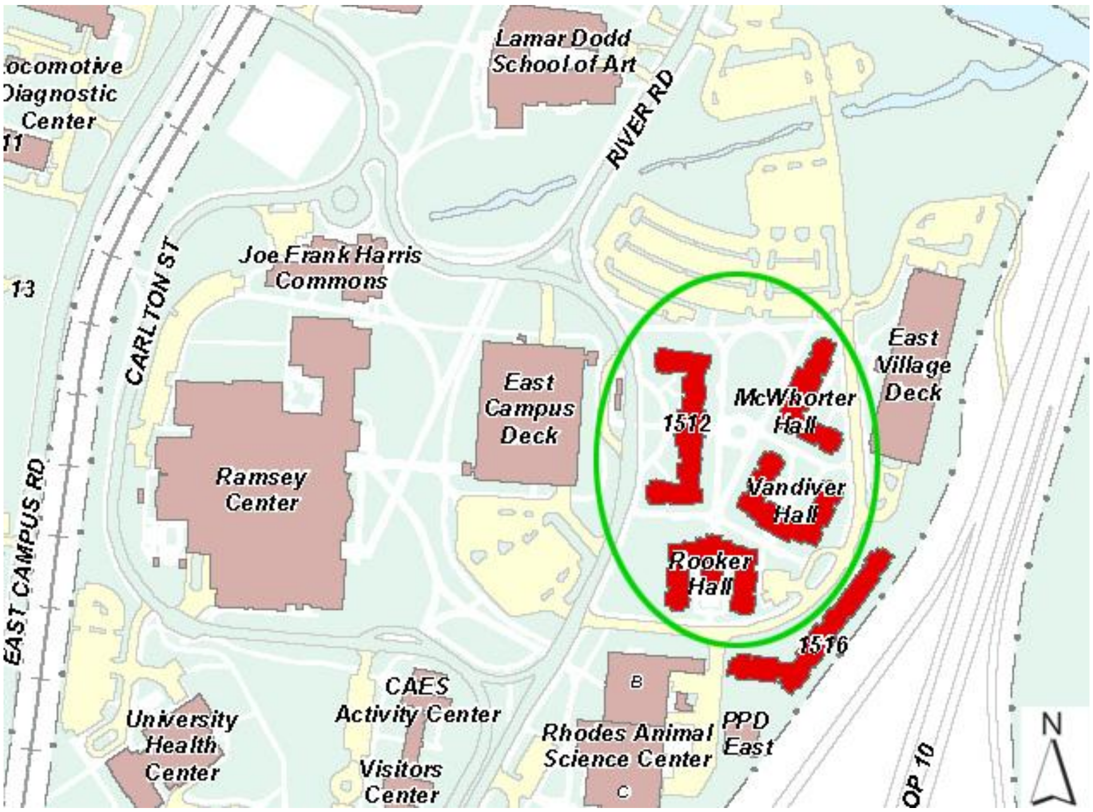


Figure 5.1 East Campus Village on UGA campus map
http://www.uga.edu/housing/

Analysis of Existing Lighting Design

Besides the wall mounted entrance lights for all building entrances (both front and back) and stair lights used for the stairs at the back entrance of Rooker Hall, only two types of light fixture are used for lighting the rest of the ECV outdoor area including all the pedestrian paths and both open and partially open spaces. One of these two types used is the 12 feet tall pole-mounted lamp (see Figure 5.2) and the other is the 3.5 feet tall bollard lamp (see Figure 5.3) which has already been phased out according to the UGA Exterior Campus Lighting Standards and Guidelines. The light source used on these fixtures is a metal halide lamp which has fairly good color rendition and is much more energy efficient than an incandescent lamp ("Exterior Campus Lighting Standards and Guidelines" 18-28).

Figure 5.2 (Image to the left) Existing pole-mounted light

Figure 5.3 (Image to the right) Existing bollard light

For easier analysis, the chosen site is divided into three areas: area I, II and III (see Figure 5.4). Area I consists the enclosed courtyard of Vandiver Hall and its front entrance. Area II consists of the grounds and the pedestrian path between McWhorter and the courtyard including the entries to the path. Area III consists of the circular open space and the space connecting the east entrance of Building 1512. There are a total of 22 lights installed at the chosen site. Five of them are pole-mounted and the rest are bollards. The locations of these lights are depicted as shown in Figure 5.5.

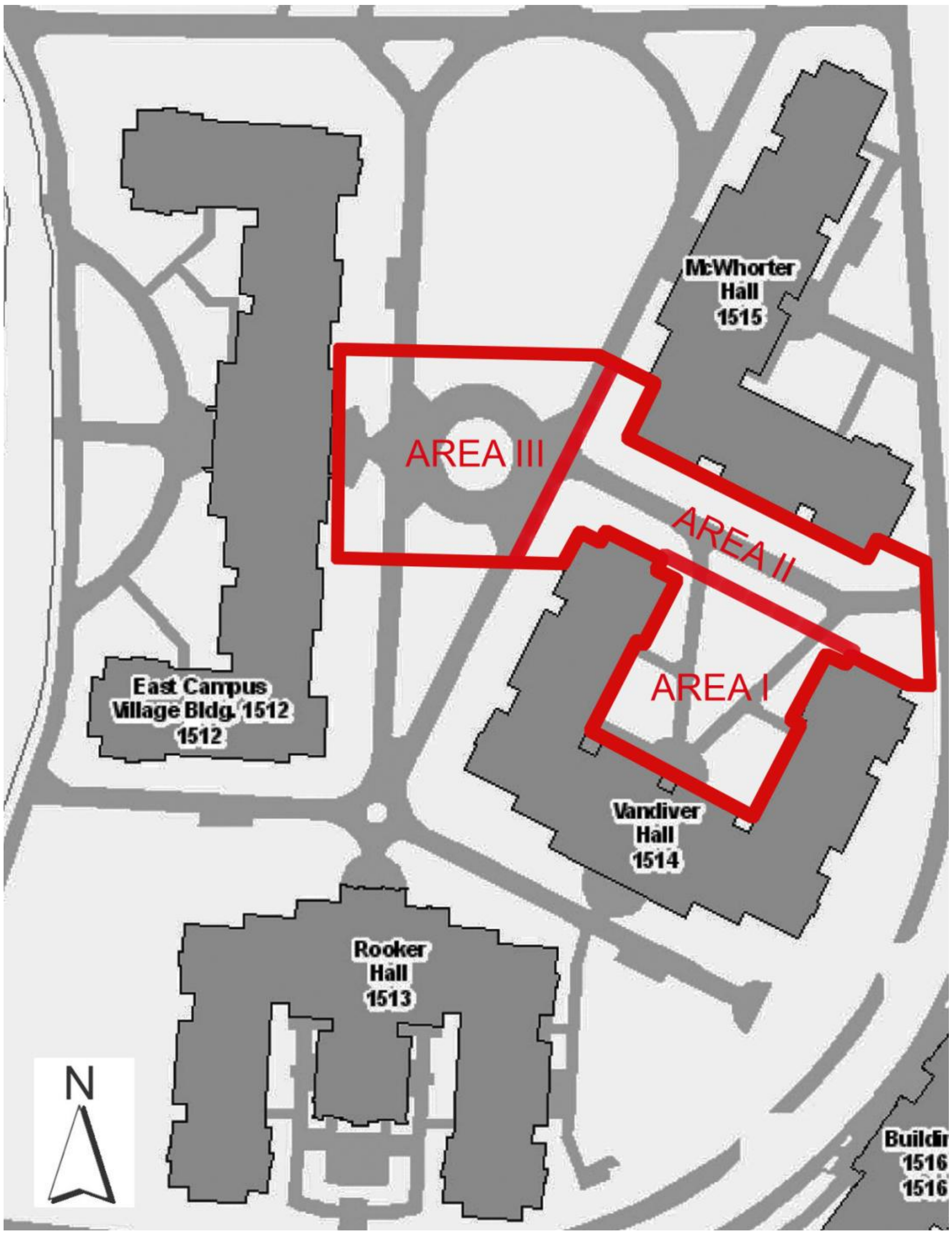


Figure 5.4 Section chosen for review and design
http://aviary.camplan.uga.edu/CampusMap/

Figure 5.5 Locations of existing lights

From observation, the existing lighting (see Figure 5.6) at the chosen site has both positive and negative features in its design. Let's first look at the positive features in the existing design. The lighting level in all three areas is sufficient for walking and other outdoor activities. The luminance difference between the lighted area and its adjacent surrounding area is small, so there are no deep shadows that may become potential hideouts. The main entrances of Vandiver Hall and Building 1512 are sufficiently lighted using both interior and exterior lighting. It feels safe to walk around in these areas at night.

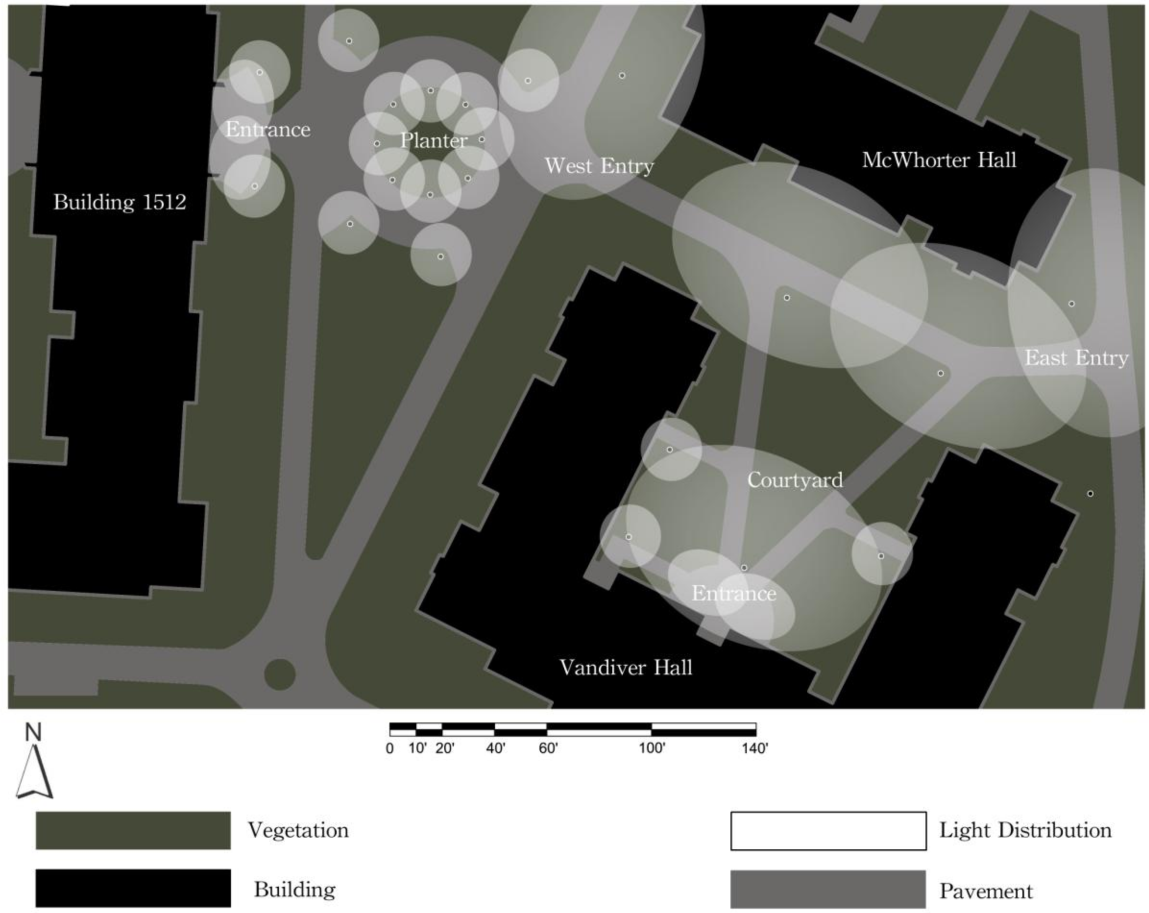


Figure 5.6 Plan view of existing lighting design

Now let's look at the problematic features in each area. In area I, the three bollard lights installed in the front courtyard of Vandiver Hall are placed very close to the building and they produce a substantial amount of light onto the adjacent windows on the lower levels (see Figure 5.7). These bollard fixtures do not provide enough shielding and the light emitted gets scattered in all directions causing an uncomfortable glare. One pole-mounted light is installed right in front of the main entrance of Vandiver Hall (see Figure 5.8) where there is already enough illumination from the wall mounted lights on each side of the doorway. It seems unnecessary where the lamp is positioned and it also creates this unsightly view into and out of the courtyard during the day and especially at night. In area II, all of the pole-mounted lights installed in this area are positioned in very close proximity to the buildings to provide illumination for the path as well as the entries to the path. These fixtures do not seem to have enough shielding capability to prevent light spill onto the windows of the adjacent residence halls as shown in Figure 5.9. A building sign for Vandiver Hall is mounted on one side of the west entry of the path, and is currently being lit by the light cast from the pole-mounted light installed on the opposite side. This sign might need additional lighting if the pole-mounted light gets removed or repositioned. A total of fourteen bollard lights are installed in area III: eight of them are placed in a circular pattern on the edge of the central planting bed where several crape myrtles and small shrubs are planted; four are positioned on the lawn surrounding the circular brick paved area, and two are installed near the front entrance to building 1512. At night, the light from the bollard lamps around the planting bed is quite obtrusive and excessive. These lights generate a small light clutter when viewed from a distance causing discomfort and confusion. The lighting design in this area neither defines the unique characteristic of the space as a central gathering place where people can converse and congregate, nor creates the atmosphere or mood for such activities.

Figure 5.7 (Image on the left) Light trespass from existing bollard light

Figure 5.8 (Image on the right) Light installed in front of Vandiver Hall

Figure 5.9 Light spills onto adjacent building

The overall experience of the nightscape at East Campus Village is not a very memorable one because it is the same monotonous lighting no matter where you look. Nothing in the landscape is highlighted or accentuated to provide for visual interest and wayfinding. Navigating through this area at night might not pose much problem for the residents that live here but it might for first time visitors. The beautifully landscaped grounds one experiences during the day fades away into the darkness of the night. The existing planting masses (see Figure 5.10) at the site do not create many places for concealment because the shrubs are densely planted against the buildings and most of these shrubs are not big enough to provide concealment for a grown person. Potential hideouts will be addressed in each proposal. Lights that are positioned too close to the buildings need to be repositioned farther away to minimize light trespass, or they need to be replaced with light fixtures that have features for optimal shielding and glare control if they stay where they are. Certain existing elements in the landscape can be lighted to create contrast and visual interest, as well as visual cues for better wayfinding. New elements such as sculptures or site furnishing can be added with subtle lighting to replace some of the existing lights to break the monotone, reduce light clutter and also create an atmosphere that encourages and generates more nighttime activities, which in turn can act as a more effective measure against crime. Colors can be introduced as well to create more fun, after all this is a living space for college students. Through careful lighting, the outdoor area of East Campus Village has a lot of potential to provide a more unique and pleasant living experience for its residents at night.

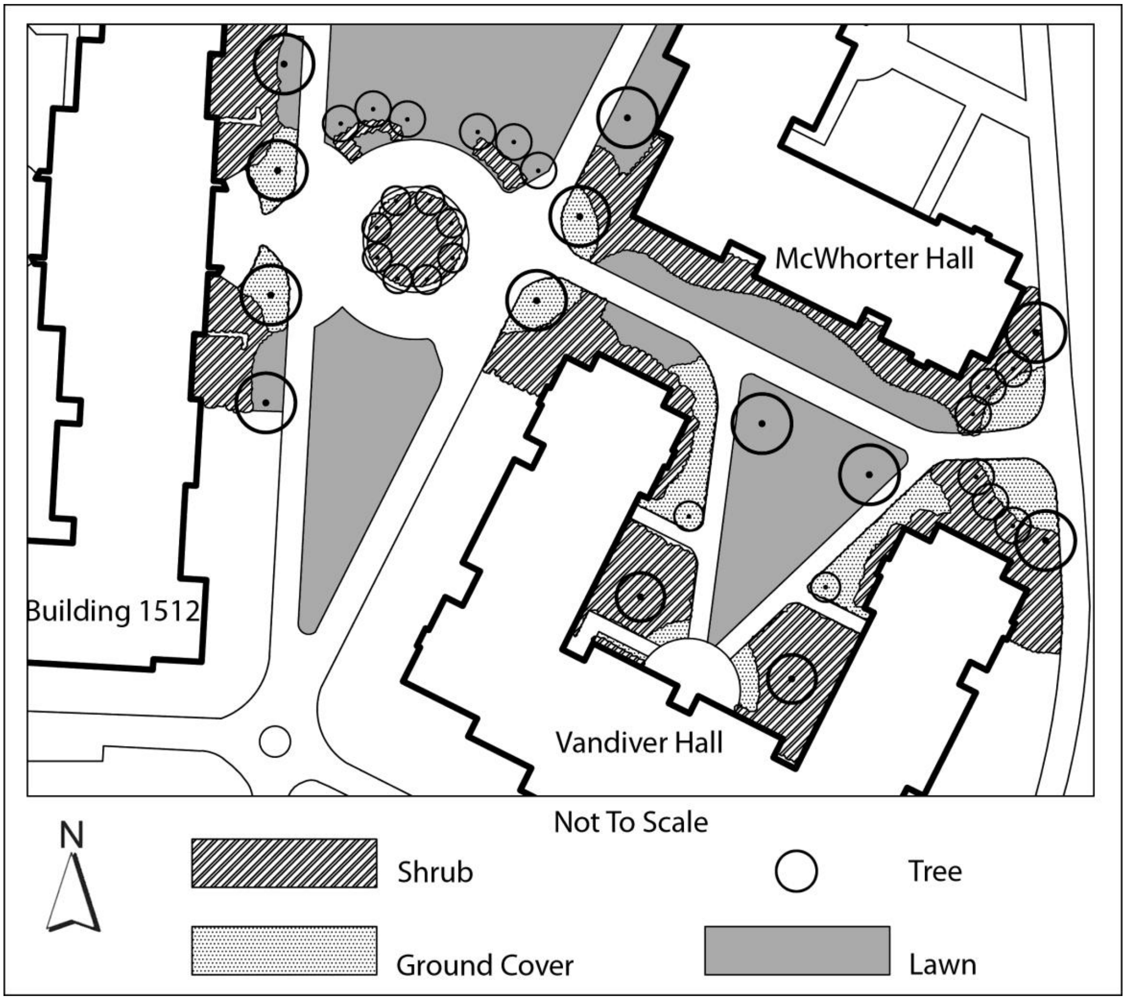


Figure 5.10 Existing planting masses for the site

Design Proposal One

Based on the review, the major lighting issues for this site include light pollution in the forms of light trespass, glare and excessive lighting (too many lights); spaces are not well defined to provide visual cues for wayfinding; there are no visual interests that might encourage more activities and attract more users. In this proposal, luminaires that have full-cutoff classification or optimal shielding and glare control devices are recommended to replace the ones that are used in the existing design in order to minimize light trespass as well as glare and light clutter. The location and position of these lights in the existing design remain intentionally unchanged to demonstrate how much difference it can make by switching to full-cutoff luminaires alone. The luminaires selected (see Figure 5.11 and 5.12) to replace the existing pole-mounted fixture and the bollard fixture both have a full-cutoff classification which will keep light trespass and glare under control. Metal halide, compact fluorescent and LED lamps are recommended to be used as the main light sources because they are more energy efficient compare to other sources and have fairly good color rendering ability.

Figure 5.11 Selected full-cutoff pole-mounted lamp
http://www.selux.com

In area I, the three bollard lights are replaced with the selected full-cutoff bollard and the pole-mounted light installed directly in front of the main entrance to Vandiver Hall is replaced with the selected full-cutoff pole-mounted fixture. The wall-mounted front entrance lights in the existing design provide sufficient illumination, and thus are kept in their original state. As illustrated in the plan view (see Figure 5.13) and the before and after views of this area (see Figure 5.14, 5.15, 5.16 and 5.17), it is apparent that light emitted from the bollards no longer shines directly on their adjacent windows. The pole-mounted light however still poses as an eye sore because of its location.

Figure 5.12 Selected full-cutoff bollard light
http://www.philipstown.info

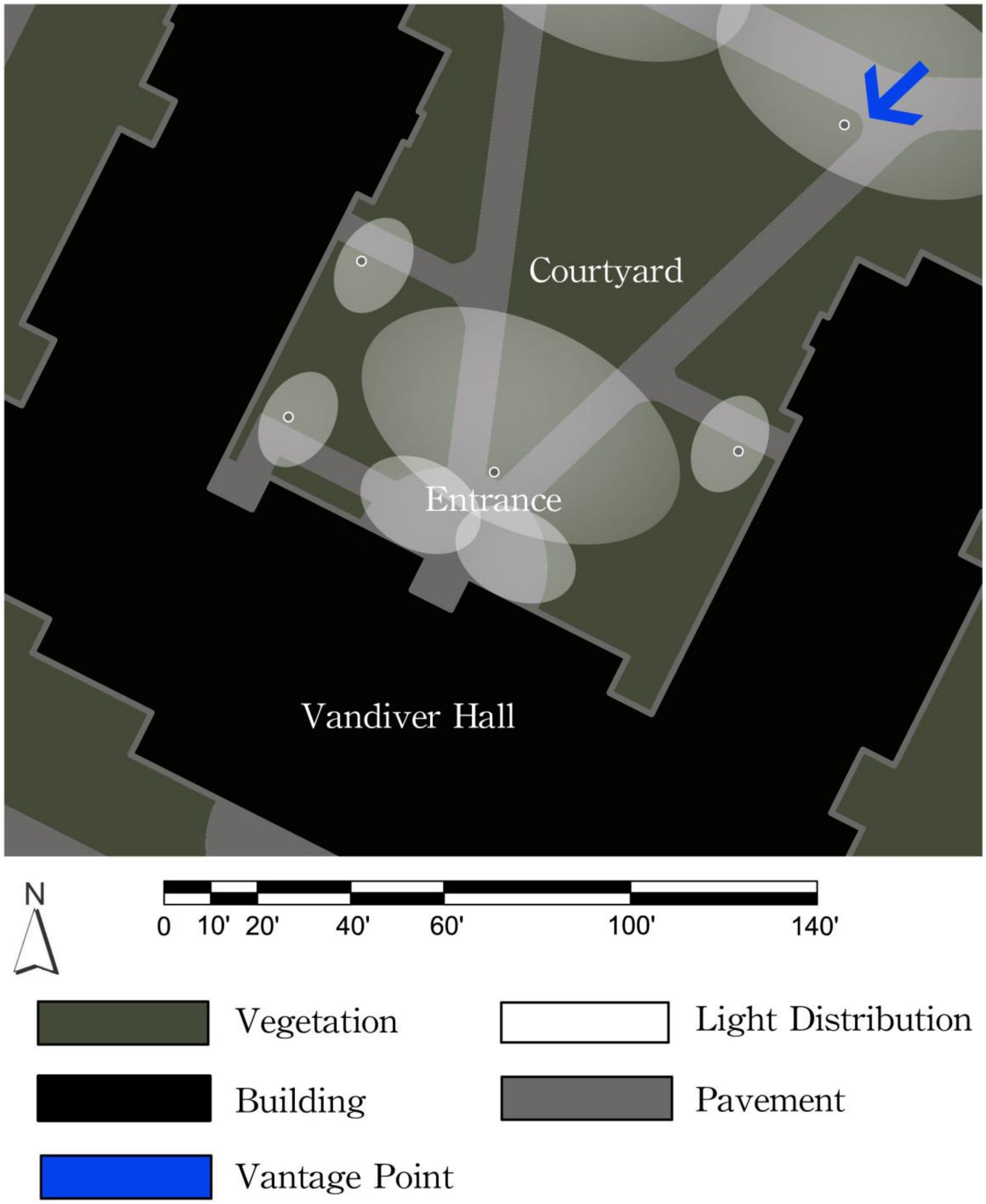


Figure 5.13 Plan view of lighting proposal one for area I

Figure 5.14 First before view of existing lighting for area I

Figure 5.15 First after view of lighting proposal one for area I

Figure 5.16 Second before view of existing lighting for area I

Figure 5.17 Second after view of lighting proposal one for area I

After replacing the existing pole-mounted lights in area II with the selected full-cutoff fixture, from the plan view (see Figure 5.18) and the before and after views of this area (see Figure 5.19 and 5.20), it is noticeable that the light trespass is greatly reduced and well under control.

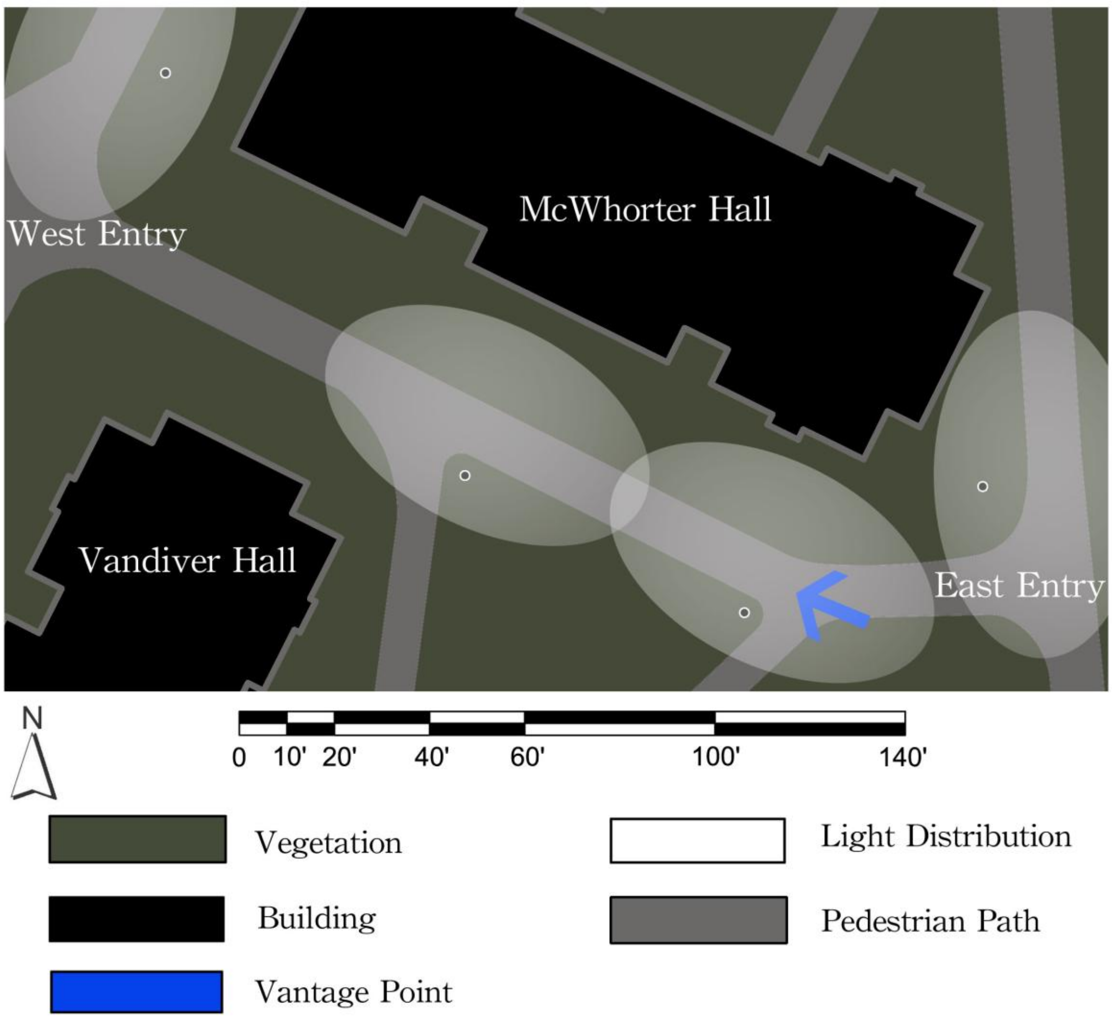


Figure 5.18 Plan view of lighting proposal one for area II

Figure 5.19 Before view of existing lighting for area II

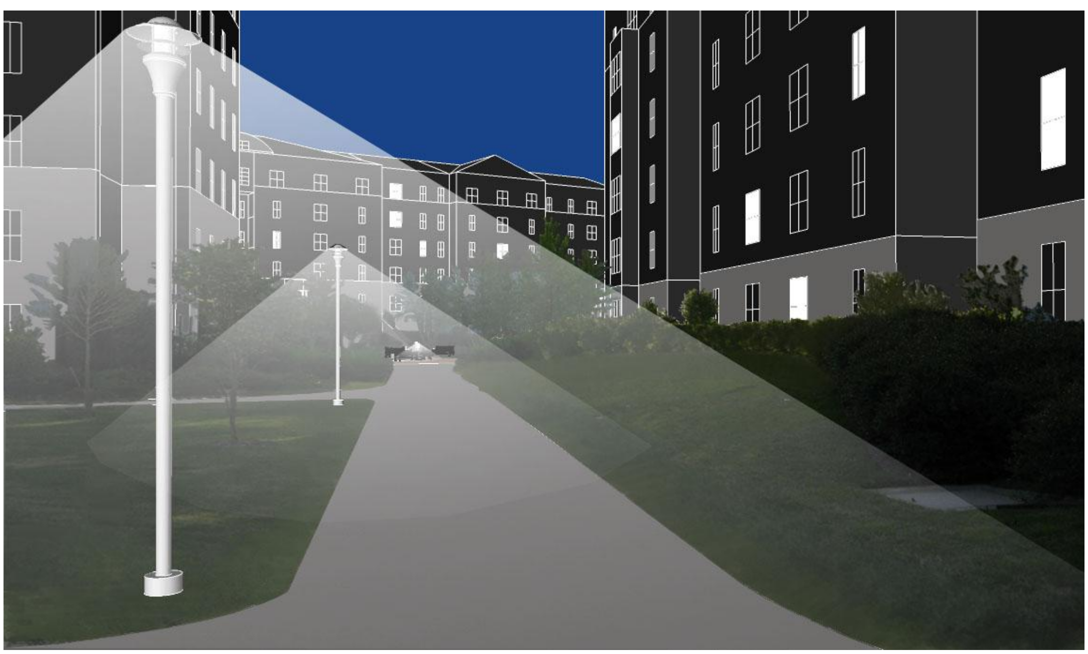


Figure 5.20 After view of lighting proposal one for area II

All of the existing bollards in area III are replaced with the selected full-cutoff bollard. As illustrated in the before and after views (see Figure 5.21 and 5.22) of this area, there is no longer a light clutter around the central planting bed and the overall lighting level is no longer excessively bright but more subtle and comfortable to the eyes. The number of lights installed in this area still seems excessive (see Figure 5.23) after replacing existing lights with full-cutoff lights. For example, the two bollards installed in front of the entrance to building 1512 can be removed because the entrance lights provide enough illumination to cover this space, and the number of lights around the circular planting bed can be reduced from eight to four, because four will provide adequate lighting for this space.

Figure 5.21 Before view of existing lighting for area III

Figure 5.22 After view of lighting proposal one for area III

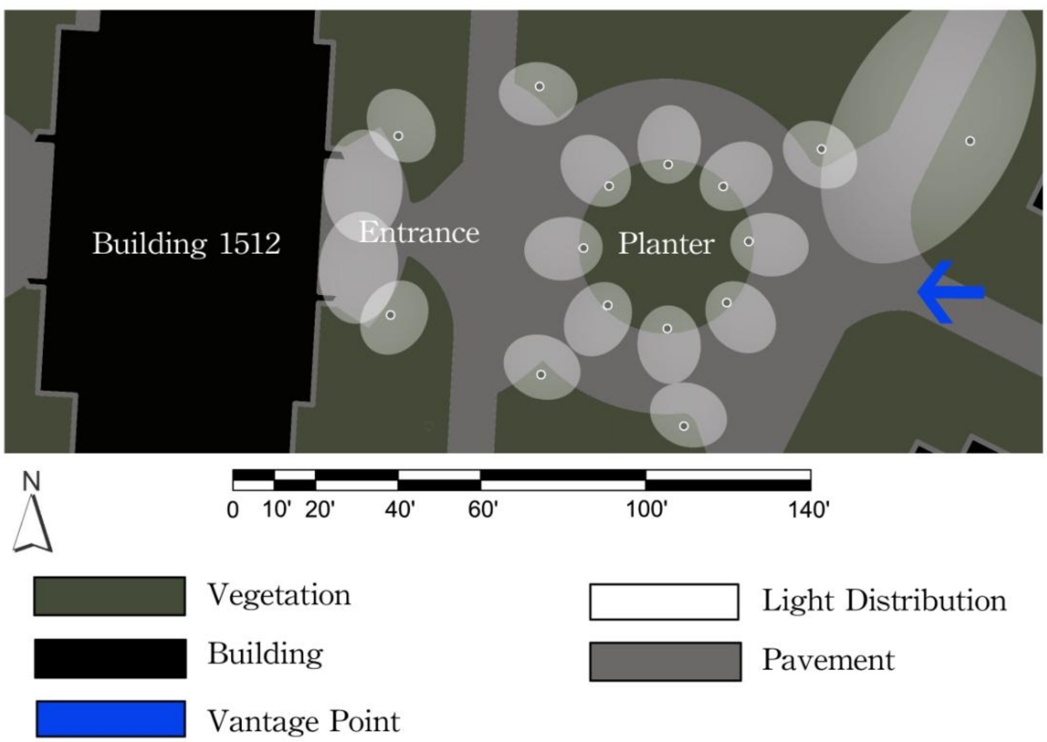


Figure 5.23 Plan view of lighting proposal one for area III

There are certainly both advantages and disadvantages in this proposal as summarized in Table 5.1. Keep in mind that the disadvantages listed are inherited from the existing design. It is apparent that even though using the appropriate lighting equipment, such as in this case full-cutoff luminaires, will keep light pollution at bay, where and how these lights should be located and incorporated into the landscape design are equally important in determining the overall effectiveness of the lighting design.

Table 5.1 Advantages and disadvantages of lighting proposal one

Advantages	1. Minimized light trespass, glare and uplight
	2. Light is more directed to its intended area
	3. The overall lighting might be more comfortable to the eyes of an viewer due to reduced glare
Disadvantages	1. Provide limited visual cues for wayfinding
	2. Some lights are excessive and are not installed where illumination is needed, thus might result in waste and extra cost of energy
	3. Does not enhance or complement the existing design of the landscape
	4. Provides very little visual interest

<u>Design Proposal Two</u>

The main concept for this design is to place lights where they are mostly needed to provide illumination for pedestrian paths, building entrances and places for activities with emphasis on minimizing light pollution, highlighting certain elements to aid visual interests and wayfinding, and creating a more inviting atmosphere to generate more activities and attract more users. Lighting is incorporated into both the hardscape and softscape to meet the lighting requirements as well as desired visual effect.

In area I, lighted cube benches (see Figure 5.24) are positioned along one side of pedestrian paths leading to Vandiver Hall. These multifunctional site furnishings designed for both sitting and lighting have one lit corner that provides soft but sufficient, and controlled lighting for the paths and their adjacent surrounding area without generating any light trespass that will intrude into the living space of student residents. LED lamps are the main sources of light for these benches. Providing sitting and lighting arrangements in this fashion will attract more users and add a modern flair to this area at night. As shown in the plan view (see Figure 5.25) and the after views (see Figure 5.26 and 5.27) of this area, lighting is concentrated on the paths and directed away from the windows. Since these benches are approximately 18 inches in height and their light is situated even lower, they might not produce enough vertical illumination for facial recognition 30 feet away. The front entrance area of Vandiver is illuminated by two wall-mounted lights and interior lights from the building lobby.

Figure 5.24 Lighted cube benches
http://theluxhome.com/tag/granite-cube-bench/

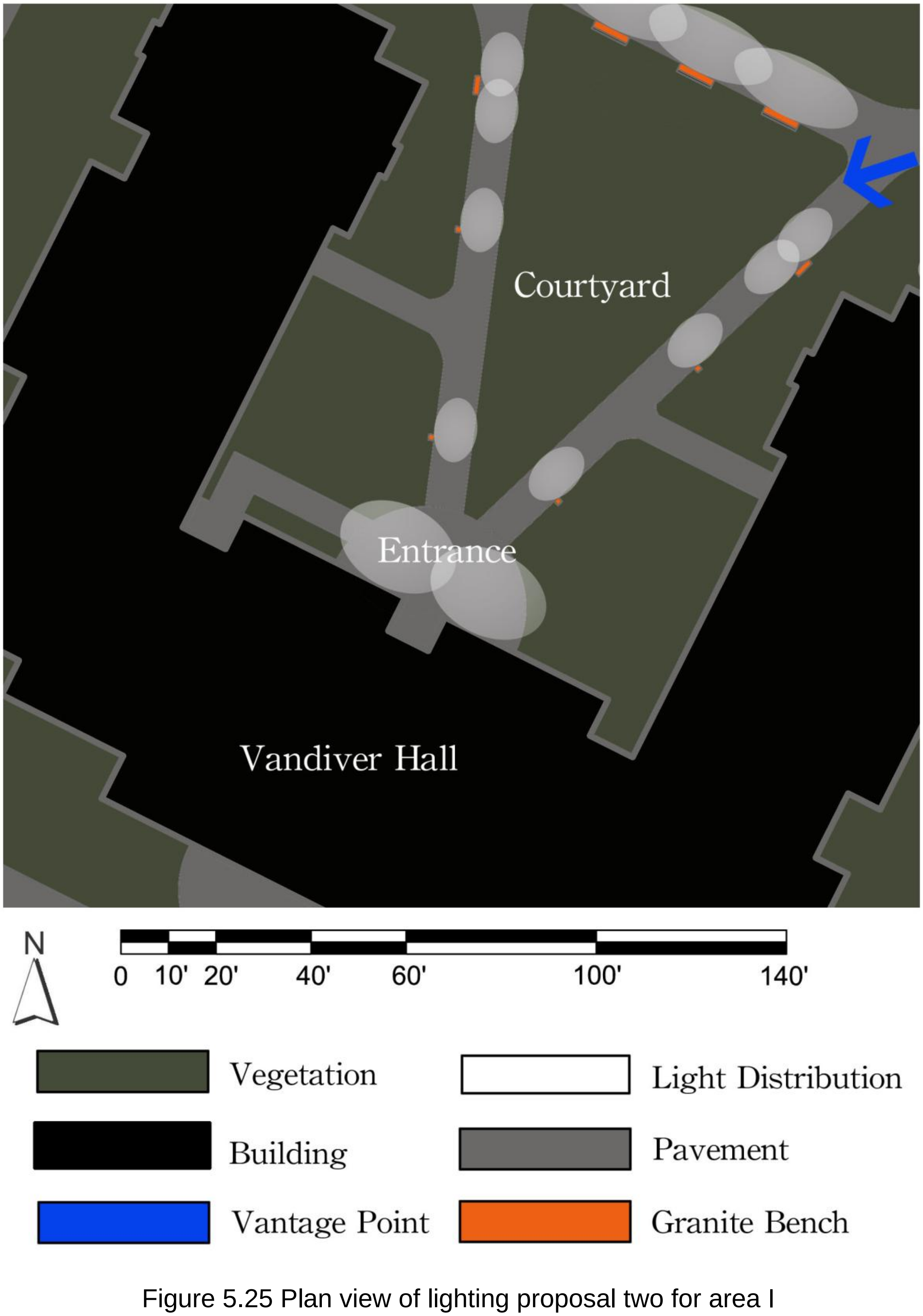


Figure 5.25 Plan view of lighting proposal two for area I

Figure 5.26 First after view of lighting proposal two for area I

Figure 5.27 Second after view of lighting proposal two for area I

In area II, three lighted granite benches are placed along the pedestrian paths to provide illumination for walking and sitting. Each bench has three LED lights installed, two on the side and one in the middle. Several LED in-ground lights such as this one shown in Figure 5.28 with glare control device are installed underneath the small shrubs at both entries of the path to provide visibility and to eliminate dark places that could become potential hideouts. ‘Glow in the dark paint’ (see Figure 5.29) is recommended to be used on the building signage for Vandiver Hall for effective readability in the dark because lighting provided in this area only highlights the plants that are planted behind this sign. As illustrated in the plan view (see Figure 5.30) as well as the after view (see Figure 5.31) of this area, light from the benches along the path only casts onto the surface of the path where people walk and no longer onto the windows of the adjacent building.

Figure 5.28 LED in-ground lights
http://www.hgtv.com/landscaping

Figure 5.29 Glow-in-the dark paint signage
http://www.glowinthedark.com.au/

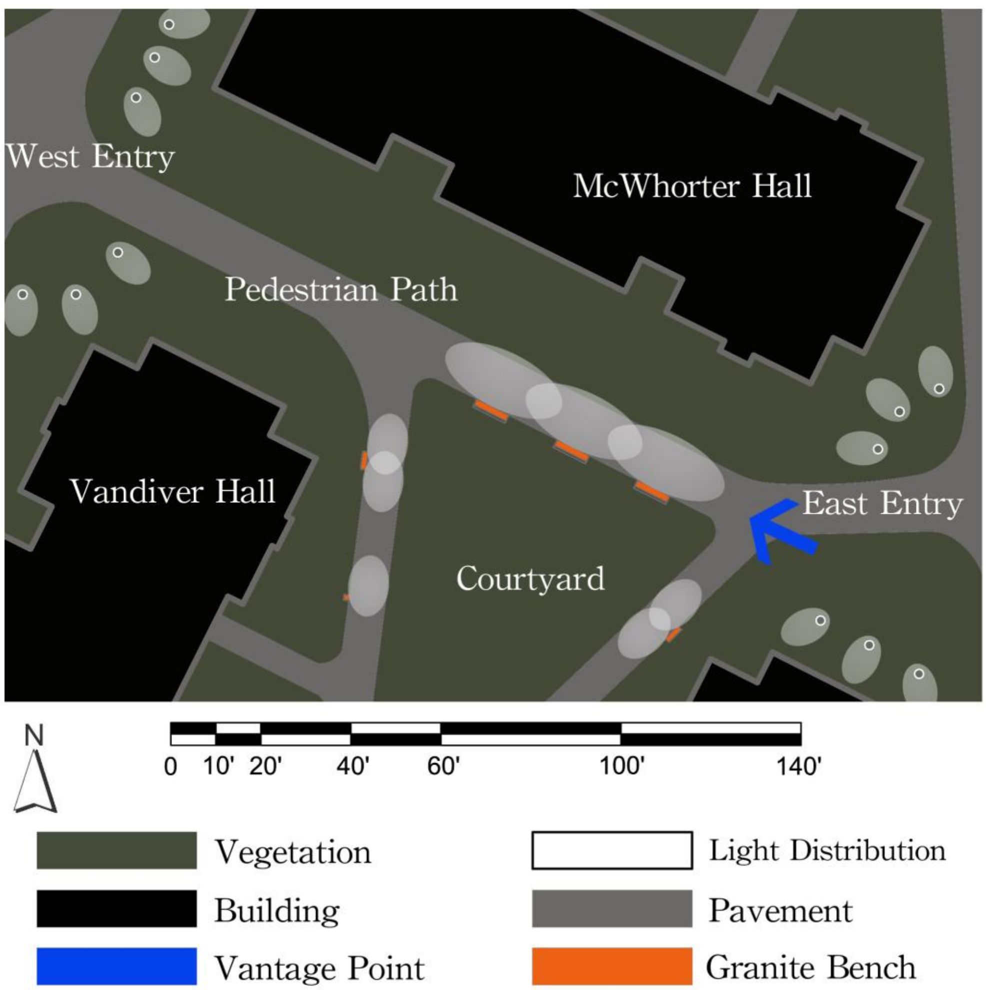


Figure 5.30 Plan view of lighting proposal two for area II

Figure 5.31 After view of lighting proposal two for area II

In area III, a seat wall is built around the circular planting bed with LED light fixtures such as this example shown in Figure 5.32 mounted under the capstone on both sides and all the way around the wall. These light fixtures are equipped with shielding devices that can keep light aimed at desired angles to prevent unwanted glare and spill. They provide sufficient illumination for this central space around the wall and also add accent lighting for the plants. Two other lighted seat walls are constructed on the outer edge of this brick paved central area abutting the lawn on opposite side to provide additional lighting as well as sitting accommodation for more activities and users. Two wall-mounted lights as well as interior lights from building 1512 provide enough illumination for this front entrance area. As seen in the after view (see Figure 5.33) of area III, this lighting configuration (see Figure 5.34) not only makes this space more inviting but also gives it a better definition as the central and focal point.

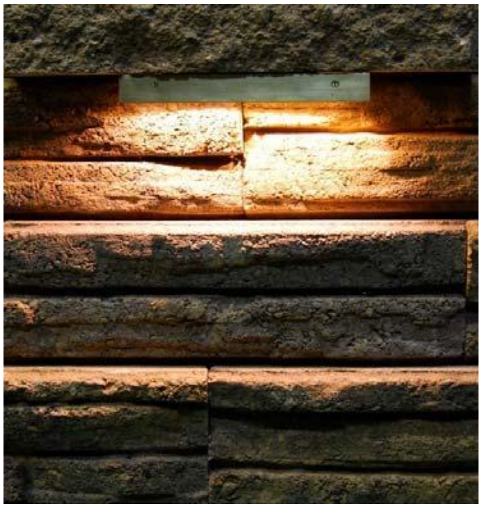


Figure 5.32 LED light fixture for hardscape
http://www.thelightingdivision.com/outdoor.htm

Figure 5.33 After view of lighting proposal two for area III

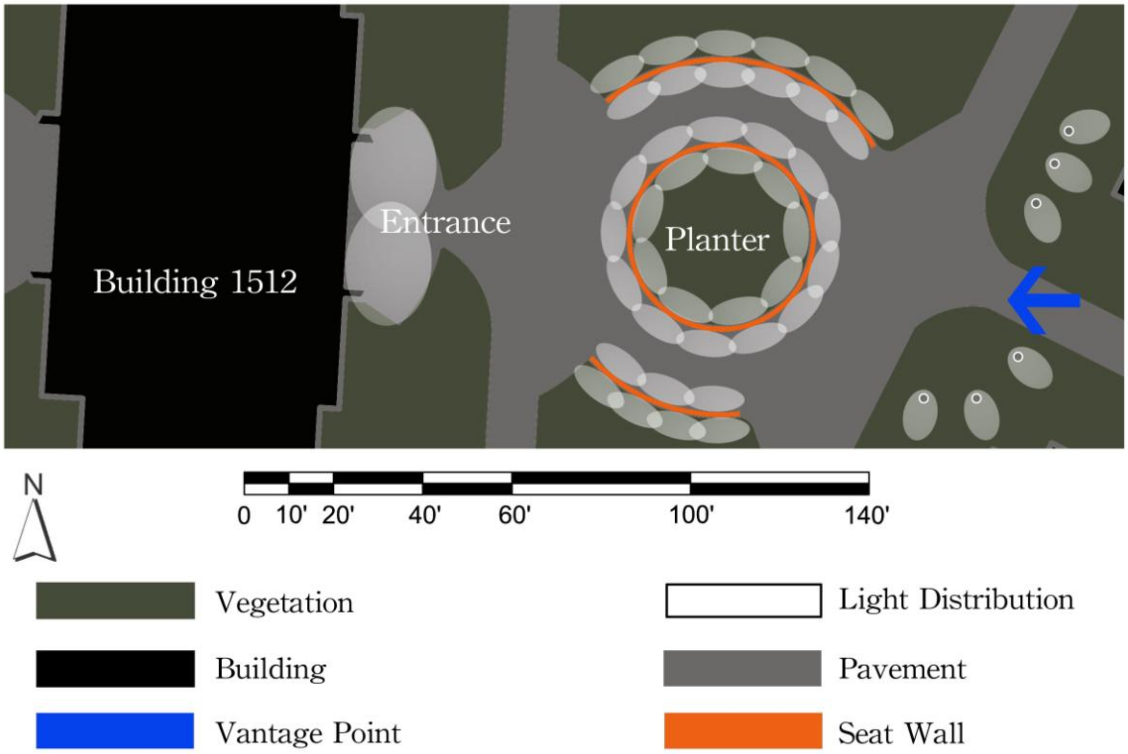


Figure 5.34 Plan view of lighting proposal two for area III

The advantages and disadvantages of this design are summarized in Table 5.2. Incorporating lighting with site furnishing is an effective way to light pedestrian paths as well as places for activities. It also helps to better define these spaces without excessive lighting and visual obstructions. Highlighting certain elements in the landscape, such as vegetation, not only provides visibility, but also adds colors and textures that bring out the essence of the landscape design at night.

Table 5.2 Advantages and disadvantages of lighting proposal two

Advantages	1. Light trespass and glare will be minimized
	2. Spaces are better defined with their intended use, thus make it easier to navigate through these spaces at night
	3. More activities will be generated, therefore perception of safety and security will be increased at night
	4. More visually interesting and attractive
	5. Multifunctional site furnishings, such as the lighted seat walls and benches provide both illumination and places to stay
	6. LED lamps are very energy efficient and durable, which in turn will save energy and maintenance costs
Disadvantages	1. Vertical illumination might not be adequate for facial recognition 30 feet away
	2. The risk of these lights being vandalized is increased because they are easily accessible to everyone
	3. A small amount of uplight will be generated by the in-ground lights for the shrubs
	4. The initial cost of the LED lamps will be more expensive than the cost of conventional light sources but they will save more in the long run

Design Proposal Three

The design concept used in proposal two is adopted in this design using a different approach in terms of material selection. The lighting equipment selected for this design includes solar self-contained LED paving lights (see Figure 5.35) that can stay illuminated for up to 12 hours, lighted LED benches (see Figure 5.36) which can be programmed to change into various shades of color, the same LED in-ground lights used in proposal two and a phosphorescent glow-in-the-dark pavement marking system (see Figure 5.37), which marks brick pavers with luminescent material that can provide 8-12 hours of illumination.

Figure 5.35 (Image on the left) Solar self-contained LED paving lights

http://www.treehugger.com

Figure 5.36 (Image on the right) LED lighted bench

http://www.treehugger.com

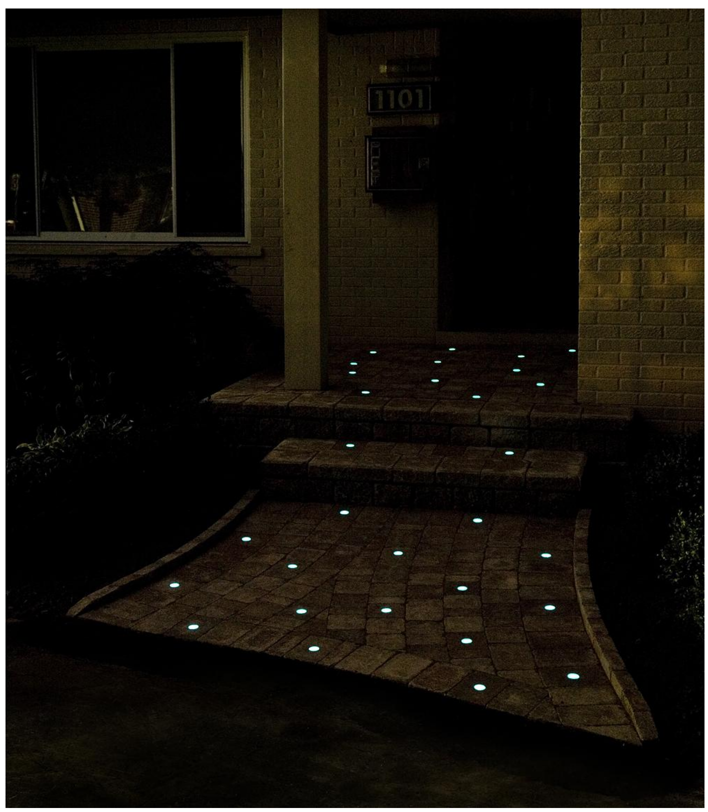


Figure 5.37 Glow-in-the-dark pavement marking system

http://www.landscapeonline.com/research/article/13230

In area I, the solar LED paving lights are installed along the edges of the pedestrian paths in the courtyard to direct the residents in and out of building safely. These lights are approximately 3 feet apart and they add accent lighting to the variety of vegetation that is planted along the path creating contrast in colors and textures. Although these lights might generate a small amount of uplight, they will keep light trespass and glare to a minimum. Two LED lighted benches are placed on either side of the main entrance area and additional illumination is provided by two wall-mounted lights by the entrance. Figure 5.38, 5.39 and 5.40 illustrate the plan view and the after views of this area.

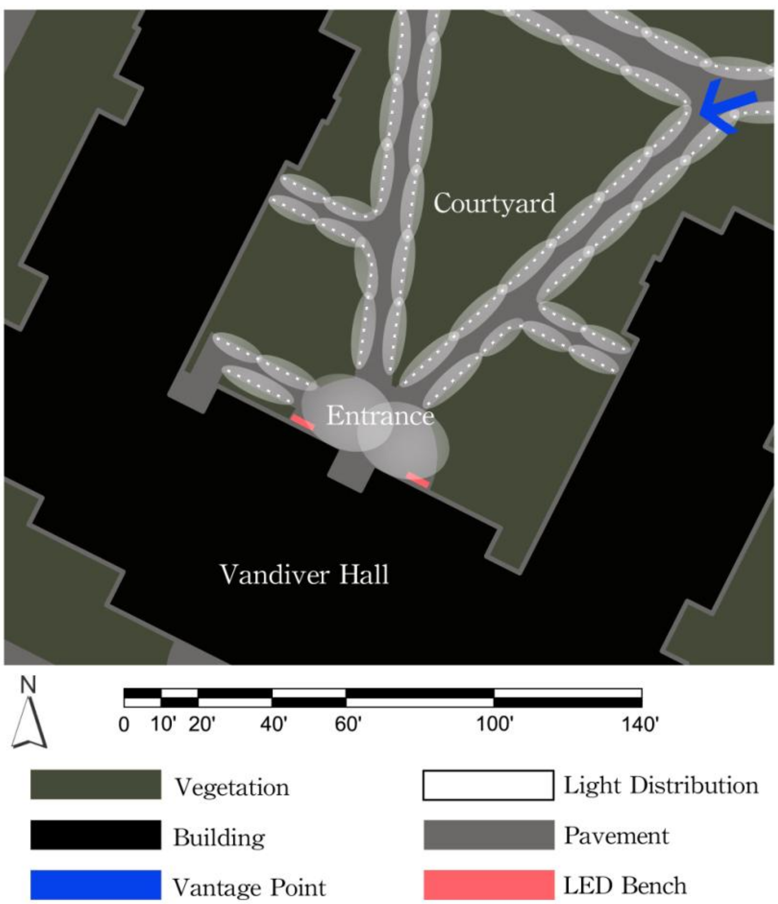


Figure 5.38 Plan view of lighting proposal three for area I

Figure 5.39 First after view of lighting proposal three for area I

Figure 5.40 Second after view of lighting proposal three for area I

In area II, illumination for the pedestrian path as well as the entries of the path is provided by installing solar LED paving lights along the edges of the path.

As shown in Figure 5.41 and 5.42, light generated by these lights stays on the path and vegetation without spilling onto the adjacent building. The illumination is sufficient for walking safely through this area and clearly defines this space.

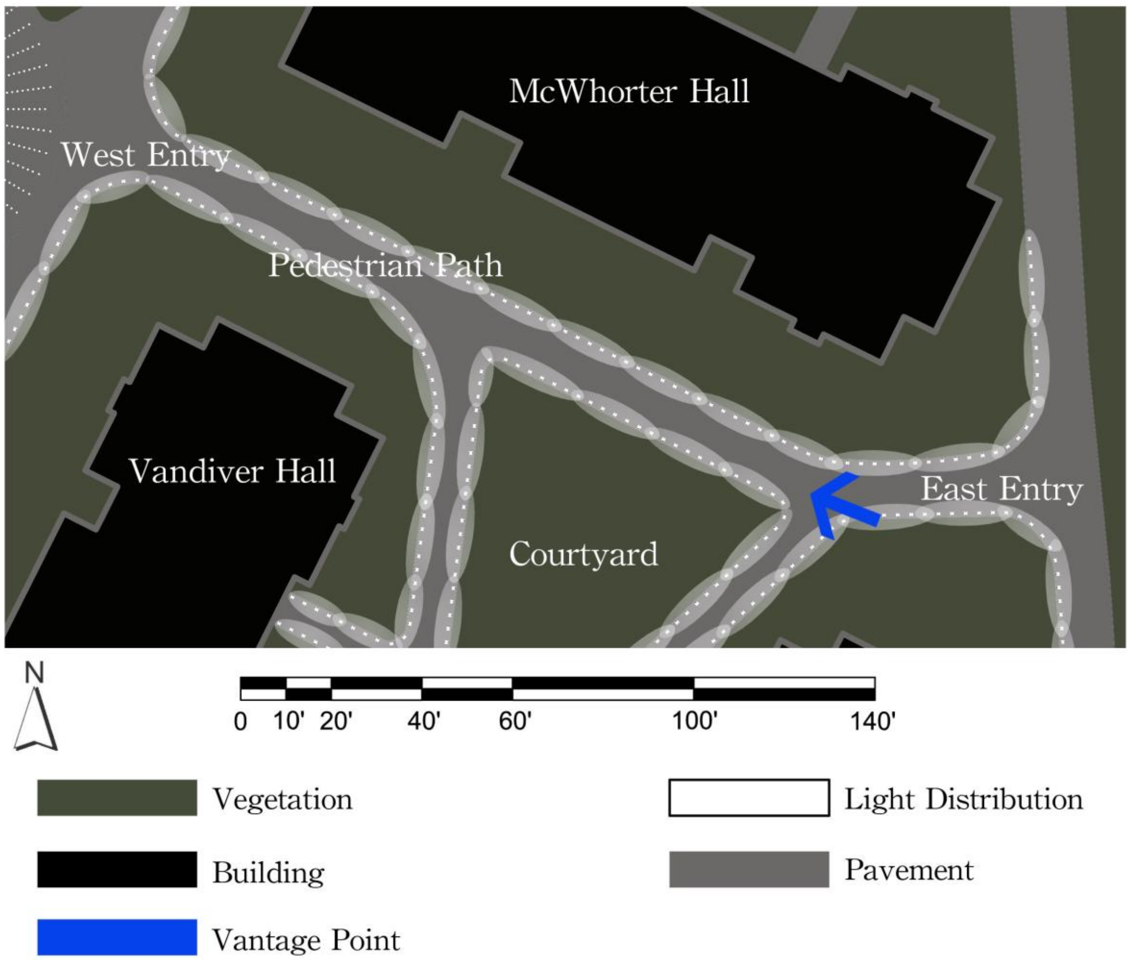


Figure 5.41 Plan view of lighting proposal three for area II

In area III, the brick paved circular open space is treated with the phosphorescent glow-in-the-dark pavement marking system and the marked pavers are arranged in a circular pattern radiating outward to mimic the stars in the night sky. Several LED lighted benches are placed around the central planting bed as well as on the north and south side of this brick paved area for a more dramatic effect. These benches add vibrant colors into this otherwise monochromatic nightscape. Several LED in-ground lights are installed to highlight the plants in the center as well as the plants on the north side of this area. Two wall-mounted lights installed at the entrance way to building 1512 and two lighted LED benches placed one on each side will provide ample illumination for this entrance area. The desired visual effect for this area is to keep the overall lighting level low with only a few highlighted elements so that the glow from pavers can be seen. As illustrated in Figure 5.43 and 5.44, the overall lighting in this area creates an interesting atmosphere that could attract more people to use this space at night.

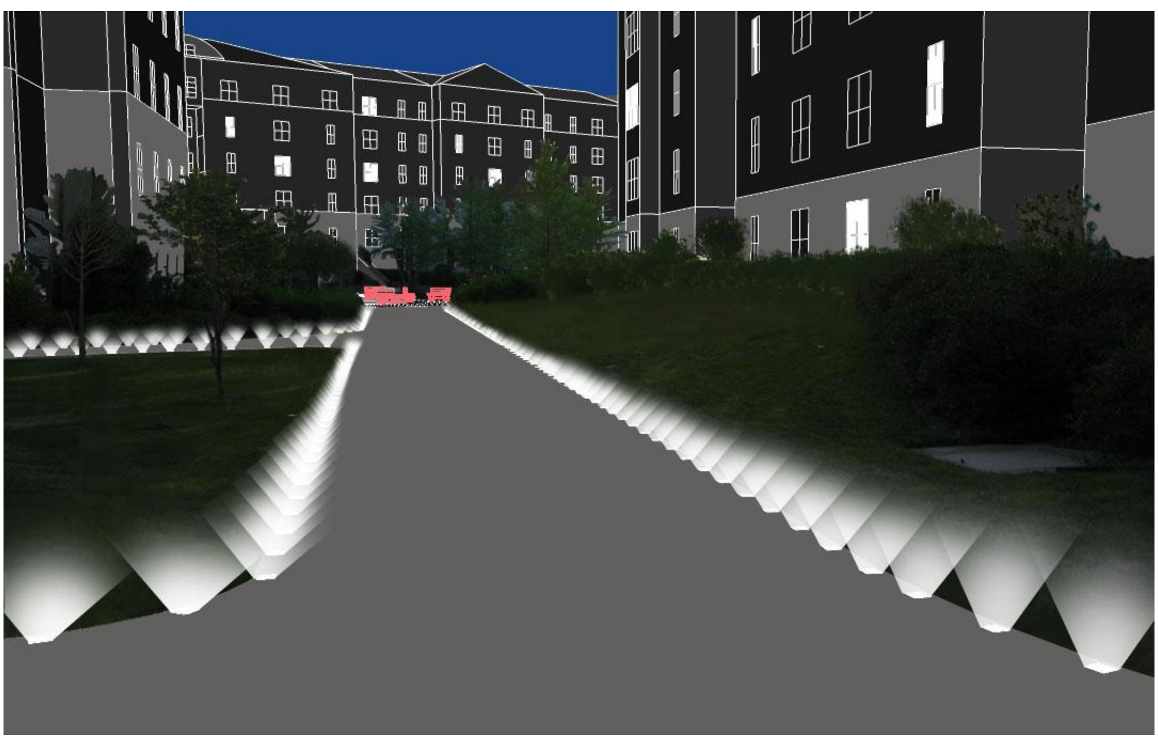


Figure 5.42 After view of lighting proposal three for area II

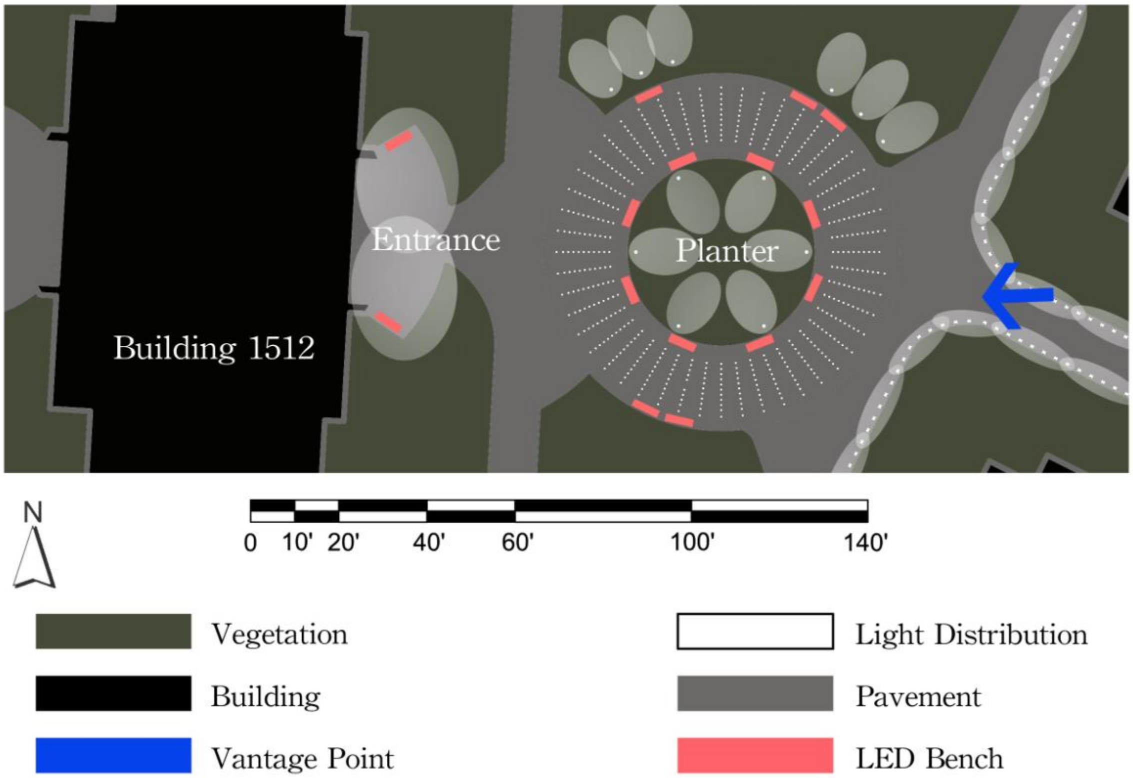


Figure 5.43 Plan view of lighting proposal three for area III

Figure 5.44 After view of lighting proposal three for area III

A summary of the advantages and disadvantages of this design is listed in Table 5.3. This design shares many similarities in advantages and disadvantages with the second proposal mainly because, as mentioned earlier, both designs are based on the same concept but with different approach in terms of material selection. There certainly will be improvement in the experience of physically walking through and spending time at these spaces as well as the experience of looking out from one of the windows at night.

Table 5.3 Advantages and disadvantages of lighting proposal three

Advantages	1. Light trespass and glare will be minimized
	2. Spaces are well defined with their intended use, thus make it easier to navigate through these spaces at night
	3. More activities will be generated and therefore perception of safety and security will be increased at night
	4. More visually interesting and attractive
	5. Multifunctional site furnishings, such as the lighted LED benches not only provide both illumination and places to stay, also create fun and joy
	6. LED lamps are very energy efficient and durable, which in turn will save energy and maintenance costs
	7. Solar paving lights are powered by the sunlight, therefore good for the environment. They will save a lot of energy and cost for maintenance
	8. The overall outdoor nighttime experience in this area will be improved and more enjoyable
Disadvantages	1. Vertical illumination might not be sufficient for facial recognition 30 feet away
	2. The risk of these lights being vandalized is increased because they are easily accessible to everyone
	3. A small amount of uplight will be generated by the in-ground lights as well as the solar paving lights
	4. The initial cost of the LED lighted benches can be expensive but they will save more in the long run

CHAPTER 6

CONCLUSION

The question this thesis seeks to answer is: what do outdoor lighting designs need to encompass in order to minimize light pollution, and simultaneously meet lighting requirements and demands presented in wayfinding and Crime Prevention Through Environmental Design (CPTED)? The objectives of this thesis are to: (1) through literature research, review and synthesize current outdoor lighting design criteria and requirements for light pollution, CPTED and wayfinding; (2) explore energy efficient lighting technologies that will offer improved supply; (3) review the current outdoor lighting at UGA East Campus Village and make alternative design proposals, so that the overall lighting quality can be improved for a community where four student residence halls are located; (4) evaluate what types of revisions to East Campus Village's lighting design were found advantageous, and consequently what types of improvements could be called for in future design practice. In finding the answer to this question and also addressing these objectives, chapter two has reviewed and synthesized the issues and lighting requirements presented in light pollution, CPTED and wayfinding; chapter three has explored energy efficient light sources and technology that can offer improved supply; chapter four has reviewed four outdoor lighting design projects that are excellent examples of what outdoor lighting design can achieve in terms of minimizing light pollution while at the same time meeting demands for wayfinding and CPTED; and chapter five has proposed three alternative design proposals to ECV's existing outdoor lighting using the strategies and criteria synthesized in chapter two.

<u>Design Critiques</u>

As summarized in chapter five, each revision to ECV's lighting design has its advantages and disadvantages. Based on the review of the existing lighting design, issues that have been identified at the chosen site include light pollution in the forms of light trespass, glare and excessive lighting (too many lights); spaces are not well defined to provide visual cues for wayfinding; and lack of visual interest that might encourage more activities and attract more users.

In proposal one, the replacement of existing luminaires with full-cutoff luminaires without changing their locations has effectively reduced light trespass and glare, and directed light to its intended area in a more controlled fashion; however other issues in the existing design are not being addressed by changing luminaires alone. These unresolved issues are listed as disadvantages (see Table 5.1) in proposal one. We have learned that although appropriate lighting materials could make a difference in keeping light pollution under control, where and how these lights are located and incorporated into the landscape design are equally important in determining the overall effectiveness of the lighting design.

In order to deal with these unresolved issues, in proposal two and proposal three, lights are positioned where they are mostly needed and away from the buildings to provide illumination for pedestrian paths, building entrances and places for activities with emphasis on minimizing light pollution, highlighting certain elements to aid visual interest and wayfinding, and creating a more inviting atmosphere to generate more activities and attract more users. In both proposal two and proposal three, instead of using the pole-mounted and bollard lights which can become visual obstructions and make the objects being lighted appear to be flat, a selection of lighting equipment that can be easily integrated into the hardscape and softscape are used to highlight key elements in the landscape such as certain vegetation, the site furnishing as well as the pavement. By incorporating lighting into the landscape design, light trespass and glare are minimized, spaces for activities are better defined for their intended tasks therefore making wayfinding easier, and the overall lighting is more visually interesting, which could generate more activities and attract more users. Light sources that incorporate LED, solar and luminescent technologies used in these two proposals could save energy as well as the cost of maintenance.

There is certainly room for improvement in both proposal two (see Table 5.2) and proposal three (see Table 5.3). One of the disadvantages is that vertical illuminance for facial recognition 30 feet away might not be sufficient because the lights used in both proposals are positioned low in the vertical plane. According to IESNA, the minimum vertical illuminance for facial identification is 0.5 – 0.8 footcandles (see Table 2.8). Since the manufacturer's specifications for these lights are not available, there is no way of knowing or even attempting to estimate the amount of vertical illumination these lights could provide. Perhaps full-cutoff bollards that do provide sufficient vertical illumination could be used in conjunction with these lights to meet that requirement. There will be a small amount of upward light emitted by the LED in-ground lights for the plants as well as the solar paving lights for the paths. The LED in-ground lights are equipped with a shielding device which can direct light to the target area without producing a significant amount of glare. The plants could work as natural shielding devices to minimize upward light emission when these lights are installed underneath them. It is impossible to estimate the amount of upward light emission the solar paving lights could generate without accurate information from the manufacturer. If necessary, reducing the numbers of these lights installed or switching to lights with lower voltage could reduce the amount of light emitted upward.

The risk of these lights (in proposals Two and Three) being vandalized is increased because they are easily accessible to everyone; however, from my personal observations, the lights damaged on UGA campus are not easily accessible to everyone and they are often installed at somewhat quiet locations where there are not a lot of people. There are 1,200 students living at ECV when school is in session so there will always be people watching and resisting this type of behavior. In addition, some of these lights, e.g. the solar paving lights, are extremely durable and can withstand all weather conditions.

LED lights are more expensive compared to conventional lights; but they are more energy efficient and can last for years, therefore saving more energy and maintenance costs in the long run.

Progress in Lighting Design

In finding out what outdoor lighting designs need to encompass in order to minimize light pollution, and at the same time meeting lighting requirements and demands presented in wayfinding and CPTED, this thesis has synthesized lighting criteria and requirements presented in all three areas so they could be used as guidelines for the revisions to ECV's outdoor lighting design. These criteria and requirements (refer to chapter two for more detail) can be briefly described as the following: conduct thorough site analysis to determine what needs to be lighted; determine the appropriate lighting level, luminance ratio and other limitations and criteria required for the various locations and tasks within the site; select appropriate lighting equipment that fulfills these lighting requirements, e.g. lighting level and luminance ratio, etc. ; select proper lighting techniques for each application and choose optimal lighting control methods and devices to turn off lights when they are not in use.

Not all the criteria and requirements synthesized in chapter two could be applied in the redesigning process because of the technical level involved. The determination of actual lighting levels, luminance ratio, lighting control, and many other limitations required is beyond the scope of this thesis.

The lighting strategies and criteria that are applied in the revisions to ECV's existing lighting design include site analysis, the review of existing lighting design, determination of what needs to be lighted, and the use of lighting equipment and techniques. Based on the review of the existing lighting and site analysis including the physical layout of the site and how the spaces within the site are used, we are able to determine that in order to minimize light trespass and clearly define these spaces, lights need to be positioned where lighting is mostly needed and away from the buildings to provide illumination for pedestrian paths, building entrances and places for activities. An overall low but sufficient lighting level is desired to ensure students get the best quality rest at night without being disturbed by light trespass through their bedroom windows. Full-cutoff luminaires are therefore implemented in proposal one and a selection of energy efficient lighting equipment that can be easily integrated into the hardscape and plantings are used in proposals two and three. The lighting technique used in proposals two and three is to integrate lights into the landscape design and position them where they are needed.

The most effective outcome achieved using these strategies is minimized light trespass in proposals two and three because by positioning and aiming lights where they are mostly needed, light is directed away from the buildings and contained within the targeted area. The second most effective outcome achieved is better defined spaces in proposals two and three because by incorporating lights into the site furnishing, the plantings and the hardscape, the essence of the landscape design is better articulated, and more visual depth and interest are created to give each space a distinctive character at night.

The least effective outcome is that the lighting equipment and techniques used for proposals two and three might not provide sufficient vertical illumination for facial recognition 30 feet away because lights are intentionally positioned low in the vertical plane along the pedestrian paths to avoid light trespass onto the adjacent buildings. Lack of vertical illumination might not pose much of a problem during the early hours of the night when many people are outside; however, it might generate fear after the outdoor areas are deserted later at night.

The lighting equipment and techniques used have produced both the most and the least effective outcome. Can light pollution be minimized without compromising safety? I think the answer is yes because lighting equipment and technique can always be changed or adjusted to meet both needs.

The overall lighting quality in the proposals has improved in terms of minimizing light pollution, providing more visual cues for wayfinding, and attracting more activities and users at night. Different types of sites could produce different results because the physical location, surroundings, existing elements, function and user populations of a site have direct impact on how it should be lighted.

Lighting design process could be hindered without knowing the actual lighting levels, luminance ratio, and other requirements. These requirements directly affect the selection of lighting materials including the types of light source and luminaire, therefore it is important to integrate lighting design early on and throughout the design process for a project so that all parties including landscape architects, architects and lighting experts are involved and ideas are communicated.

REFERENCES

Atlas, Randall I. *21st Century Security and CPTED*. United States: Taylor and Francis Group, 2008. Print.

Bordas, David Bravo. "Plaza del Torico." *Public Space.* 2007.Web. <http://www.publicspace.org/en/works/e152-plaza-del-torico>.

Cilento, Karen. "The New York High Line Officially Open." *Arch Daily.* 9 June 2009Web. <http://www.archdaily.com/24362/the-new-york-high-line-officially-open/>.

"Citygarden." *Citygarden.* 2009.Web. <http://www.citygardenstl.org/>.

"Citygarden a Splashing Civic Success." *Hydro Dramatics.*Web. <http://hydrodramatics.com/citygarden-st-louis.htm>.

"Citygarden by Fisher Marantz Stone and Randay Burkett Lighting Design." *Magazine Enlighter.* 18 July 2010Web. <http://www.enlightermagazine.com/projects/citygarden-fisher-marantz-stone>.

Crowe, Timothy. *Crime Prevention through Environmental Design*. Second ed. United States: Butterworth-Heinemann, 2000. Print.

"East Campus Village." *UGA Housing.*Web. <http://www.uga.edu/housing/tour/east.html>.

"Exterior Campus Lighting Standards and Guidelines." *University Architects for Facilities Planning.* 2011.Web. <http://www.camplan.uga.edu/pdf/Exterior%20Campus%20Lighting%20Standards%20and%20Guidelines%202011.pdf>.

Fehrenbacher, Jill. "Interview: Architect James Corner on NYC's High Line Park." *Inhabitat.* 23 Aug 2010Web. <http://inhabitat.com/interview-architect-james-corner-on-the-design-of-high-line/>.

Fleming, Nic. "Night-shift Women Face Cancer Risk." *The Telegraph.* 2 Dec 2005Web. <http://www.telegraphindia.com/1051202/asp/atleisure/story_5549239.asp#top>.

Goetzberger, A. and V.U. Hoffmann. *Photovoltaic Solar Energy Generation*. Germany: Springer, 2005. Print.

Green, Martin. *Power to the People*. Australia: UNSW Press, 2000. Print.

"The High Line, Section 1." *General Design 2010 ASLA Professional Awards.*Web. <http://www.asla.org/2010awards/173.html>.

Howard, Brian Clark, William J. Brinsky, and Seth Leitman. *Green Lighting*. United States: McGraw-Hill, 2011. Print.

IESNA G-1-03. *Guideline for Security Lighting for People, Property, and Public Spaces*. New York: IESNA, 2003. Print.

IESNA RP-33-99. *Lighting for Exterior Environments an IESNA Recommended Practice*. New York: IESNA, 1999. Print.

IESNA RP-8-00. *American National Standard Practice for Roadway Lighting*. IESNA, 2000. Print.

IESNA TM-15-07. *Luminaire Classification System for Outdoor Luminaire*. New York: IESNA, 2007. Print.

IESNA. *The IESNA Lighting Handbook Reference and Application*. Ninth ed. New York: IESNA, 2000. Print.

Institution of Lighting Engineers. "Guidance Notes for The Reduction of Obtrusive Light " *British Astronomical Association.* 2005.Web. <http://www.britastro.org/dark-skies/pdfs/ile.pdf>.

International Energy Agency. *Light's Labour's Lost*. OECD/IEA, 2006. Web.

Klots, Irene. "City Lights Spike Air Pollution." *Discovery News.* 17 Dec 2010Web. <http://news.discovery.com/earth/city-lights-air-pollution-101217.html>.

"Light Pollution." *Lighting Answers* 7.2 (2007)*National Lighting Product Information Program.* Web. 20 Jan 2011.

"Light Pollution and Energy." *International Dark-Sky Association.* July 2009 2009.Web. 12 Dec 2010 <http://www.darksky.org/mc/page.do?sitePageId=90127>.

"Light Pollution and Safety." *International Dark-Sky Association.* Dec 2010Web. <http://docs.darksky.org/PG/ida_safety_brochure.pdf>.

"Light Pollution and Wildlife." *International Dark-Sky Association.* 2008.Web. <http://www.darksky.org/mc/page.do?sitePageId=90127>.

"Lightscape / Night Sky." *NPS.gov.* 12 Jan 2009Web. <http://www.nps.gov/arch/naturescience/lightscape.htm>.

"Lure of the Dark Side." *FX the business of design.* 2011.Web. <http://www.fxmagazine.co.uk/story.asp?storycode=3487>.

Narisada, Kohei, and Duco Schreuder. *Light Pollution Handbook*. The Netherlands: Springer, 2004. Print.

"Natural Lightscape Management." *National Park Service Explore Nature.* 15 Jan 2007Web. <http://www.nature.nps.gov/air/lightscapes/mgmt.cfm>.

"Outdoor Lighting and Safety." *Illinois Coalition for Responsible Outdoor Lighting.* 28 Feb 2011Web. <http://www.illinoislighting.org/safety.html>.

"Outdoor Solar Lighting." *U.S. Department of Energy Energy Efficiency and Renewable Energy.* 9 Feb 2011Web. <http://www.energysavers.gov/your_home/lighting_daylighting/index.cfm/mytopic=12170>.

"Overview of Outdoor Area Lighting." *U.S. Department of Energy Energy Efficiency and Renewable Energy.* 4 Aug 2010Web. <http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/outdoor_area_lighting.pdf>.

"Project Queen's Walk, South Bank." *Speirs and Major.* 2010.Web. <http://www.speirsandmajor.com/work/architecture/queens_walk/>.

Raphael, David. "Wayfinding Principles and Practice." *Landscape Architecture Technical Information Series Number 2* (2006)Web.

Renewables 2010 Global Status Report . Paris:, 2010. *Renewable Energy Policy Network for the 21st Century.* Web.

Renzi, Jen. "Plaza del Torico." *Architectural Record.* 2011.Web. <http://archrecord.construction.com/projects/lighting/archives/0808plaza-1.asp>.

Rich, Catherine, and Travis Longcore, eds. *Ecological Consequences of Artificial Night Lighting*. Ed. Rich, Catheriane, and Travis Longcore. Washington, DC: Island Press, 2006. Print.

Sheftell, Jason. "He Turns On NYC: Lighting Designer Herve Descottes's Bright Ideas Light Up the City." 1 Oct 2010Web. <http://articles.nydailynews.com/2010-10-01/news/27076832_1_water-and-light-l-observatoire-international-columbus-circle/2>.

Stevens, Richard G. *Artificial Lighting in the Industrialized World: Circadian Disruption and Breast Cancer*. Springer, 2006. *SpringerLink.* Web.

Watson, Donald, Alan Plattus, and and Robert G. Shibley, eds.,. *Time-Aver Standards for Urban Design*. Eds. Donald Watson, Alan Plattus, and and Robert G. Shilbley. United States: McGraw-Hill, 2003. Print.

Zelinka, Al and Dean Brennan. *Safescape: Creating Safer, More Livable Communities through Planning and Design*. Chicago: Planners Press, 2001. Print.