Outdoor lighting: Sustainable practices for effectively restoring the night

by

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Abstract

Artificial lighting at night has lasting negative impacts on humans, animals, and the environment. This report aims to review and analyze existing and emerging sustainable practices in outdoor lighting that can aid in effectively restoring the night. The analysis of this report is focused on lighting quality metrics and sustainability. Other issues are discussed briefly but the main focus of this report is night sky issues. Through a comprehensive literature review and empirical analysis, the causes, effects, and potential solutions to light pollution are discussed. A review of current standards, codes, and guidelines is also included. Furthermore, an example demonstrating the recommended design goals discussed throughout the report is detailed. This report finds there is a vast potential for drastic energy conservation within exterior lighting design utilizing the combination of emerging technologies for a comprehensive, adaptable solution to better protect the night sky. This research analyzes the trajectory of the industry and how to best apply the tools at designers' disposal. The findings of this report can be used both to guide individual lighting design as well as to help further the path that standards and committees are trying to pave in order to effectively minimize light pollution and its effects.

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List of Abbreviations

AHJ - Authority Having Jurisdiction

AI - Artificial Intelligence

ALAN - Artificial Lighting at Night

AMA – American Medical Association

ASHRAE - American Society of Heating, Refrigerating and Air Conditioning Engineers

CCT - Correlated Color Temperature

CIE - International Commission on Illumination

CMS - Central Management System

FC - footcandles

IALD - International Association of Lighting Designers

IDA - International Dark-Sky Association

ICC - International Code Council

IECC - International Energy Conservation Code

IES - Illuminating Engineering Society

LEED AP – Leadership in Energy and Environmental Design Accredited Professional

LC - Lighting Certification

LP - Lighting Practice

RP - Recommended Practice

SDG - Sustainable Development Goal

W - Watt(s)

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To my parents, Adam and Teresa Kinder, to whom this report is dedicated. You have always been my biggest cheerleaders and have supported me through everything, even when I felt like I didn’t deserve it. To God, who has shown up for me time and time again. To whom everything in my life is dedicated. To my brother who has supported me his whole life, albeit sometimes begrudgingly. To Nathan, who patiently sat with me through the stress and helped me see the light at the end of the tunnel. I love you. To my community of friends, whom I consider family, for showing me who I could be and for supporting me on my journey to getting there. To my extended family members who have always been there for me. To my classmates and peers for laughing with me through the stress and heavy workload.

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Introduction

In a time governed by technology and continual urban expansion, the issue of outdoor lighting and its impact on the natural environment has gained traction. The excessive sky glow of artificial lighting not only threatens our ability to appreciate the true night but also poses environmental, health, and energy challenges. Striving for high quality and sustainable practices in outdoor lighting is not merely an endeavor to protect our view of the night sky but a commitment to reduce energy consumption, mitigate light pollution, and promote a healthier relationship between humans and the evening environment. This report delves into the intricate industry of outdoor lighting and explores the crucial need for implementing sustainable practices into exterior lighting design.

Through an examination of the relationship between technology, design, and policy, this report seeks to shed light on the path toward keeping our nights functional and natural. This report is a comprehensive discussion on sustainable exterior lighting largely aimed at designers. It is meant to provide easy reference as a catch-all of information on this topic.

This report aims to discuss artificial lighting at night, the need for sustainable outdoor lighting, the impacts that artificial lighting has, and sustainable practices that can be implemented into lighting design. The organization of this report is outlined as follows. The Night Sky Issues section will dive into why this topic is an issue, including its impact on the environment, wildlife, and health. The Review of Design Documents section will detail the recommendations from IES regarding outdoor lighting. The Review of Codes and Standards section will detail the recommendations and requirements of applicable codes and standards. The Basic Needs for Outdoor Lighting section will discuss the need for outdoor lighting, and why removal of all artificial lighting at night is not a viable solution. The Control Considerations section will introduce emerging technologies within the outdoor lighting industry and how current technology can be better implemented for outdoor usage and energy savings. The Recommendations section will walk through an example of the suggested design goals discussed throughout the report evaluating an existing system and, finally, the Conclusion section will summarize the findings of the report.

Night Sky Issues

Artificial lighting at night (ALAN) has negative human health, environmental, and wildlife impacts. Humans are physically and mentally affected, as well as plants, mammals, birds, and sea life, among others. The multifaceted effect of this issue adds to the urgency to solve the urban evening environment problem. In addition to physical impacts, ALAN also impacts how humans experience the evening environment. The night sky as referenced to in this report is described as the appearance of celestial objects (stars, planets, the moon) in the sky after the sun sets.

The Illuminating Engineering Society (IES) and the International Dark Sky Association (IDA) jointly adopted the Five Principles for Responsible Outdoor Lighting in 2020. These principles are key to achieving well designed outdoor lighting and reducing light pollution. The first principle, useful, indicates that all lighting should have a clear purpose (IES, 2022b). The second, targeted, states that light should be aimed only where necessary (IES, 2022b). The third, low light levels, asserts that illumination should be no higher than necessary (IES, 2022b). The fourth, controlled, means lighting should only be utilized when useful by way of automatic controls. And lastly, the fifth principle, color, asserts that warmer color temperatures should be used when possible (IES, 2022b). While these principles seem fairly simple by nature, they are impactful and create a stable foundation by which this report aims to build upon.

Light pollution is becoming a buzzword within the building and design industry. The more urbanized the world becomes, the more artificial lighting is utilized in outdoor spaces. Without careful design considerations, the world will have even more dark sky issues. "Right now, the planet has never been brighter in recorded history" (Slade, 2022). More than 99% of

American populations and more than 80% of the world population is being affected by light pollution (Falchi et al., 2016).

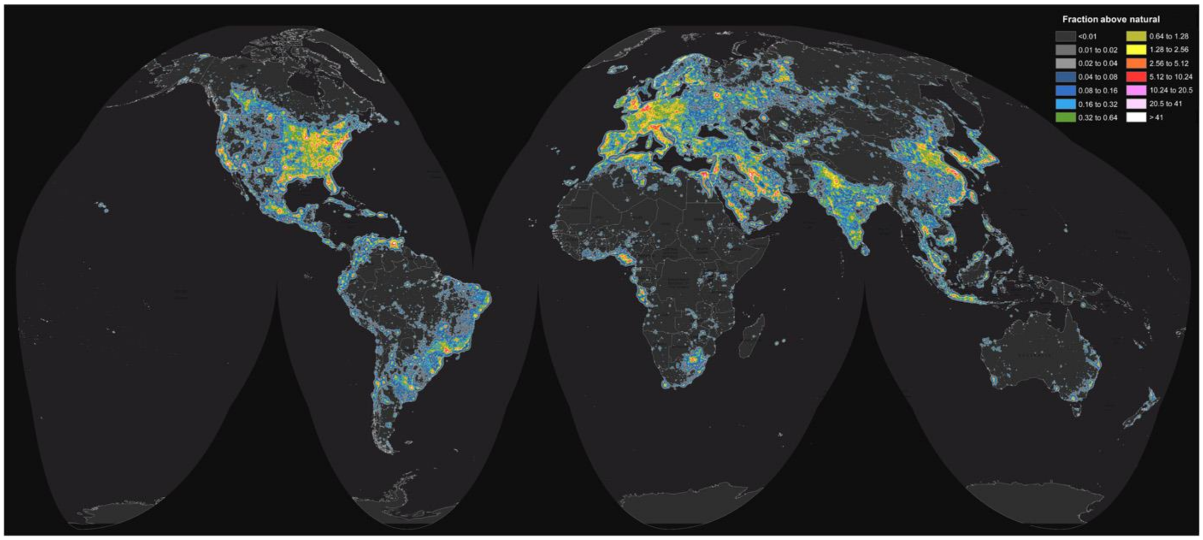

Figure 1 - World map of artificial sky brightness (Falchi et al., 2016).

Continual night-time lighting is directly impacting the way the natural environment is experienced. Artificial lighting at night (ALAN) is not only causing direct harm, but it is also inhibiting the ability to enjoy the beauty of natural darkness. The New World Atlas of Artificial Night Sky Brightness states, "Light pollution is one of the most pervasive forms of environmental alteration" (Falchi et al., 2016). In addition to being one of the most penetrating types of pollution, it is also one of the quickest to resolve. As soon as excessive light is removed, the impacts of this light begin to fade, unlike other types of pollution that can take many years to be restored.

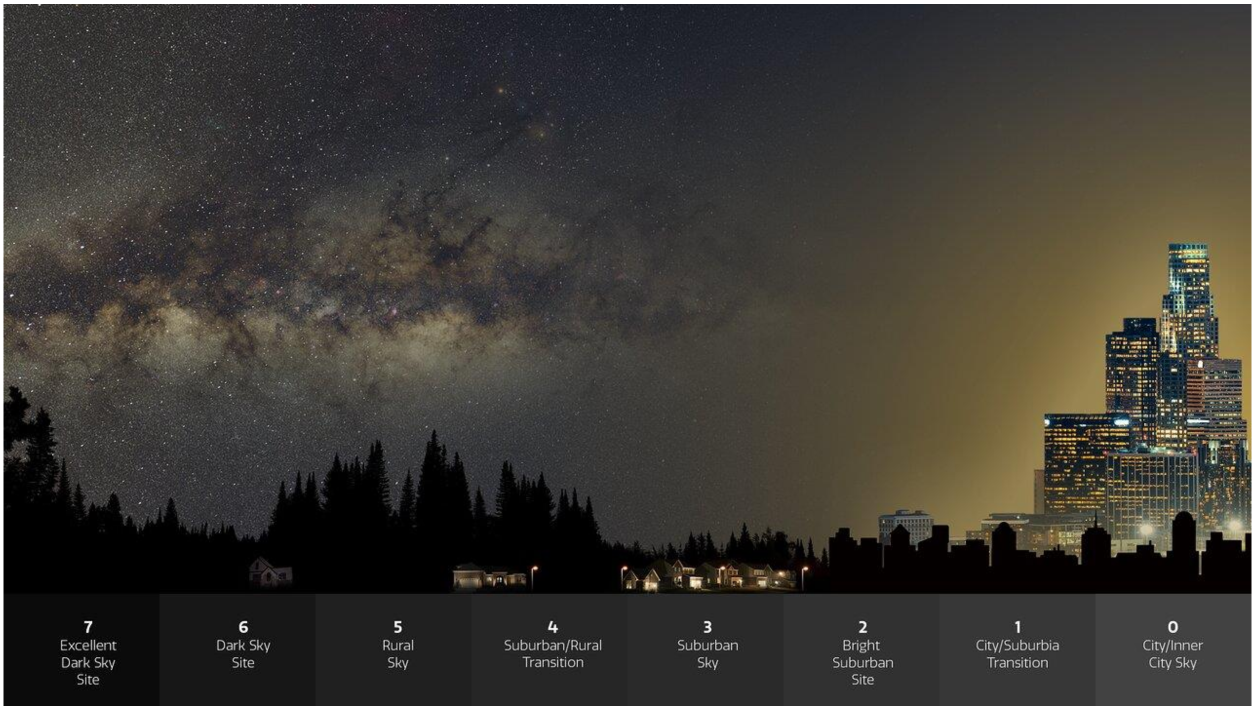

Figure 2 - Sky glow (Marenfeld, 2023).

Researchers and astronomers are developing methods to provide consistent, functional ways to compare observations of the night sky. Most of these scales range from 0 to 7 or 9, indicating the level of skyglow. One such tool that astronomers use is the Stellar Magnitude scale, shown in Figure 2. Another scale that was developed is the Bortle scale (Bortle, 2001). With both of these scales, the higher the number, the more the night sky becomes observable.

The visibility of the night sky is not the only impact of light pollution and sky glow. “When we rapidly change fundamental environmental factors such as light and temperature, we create harm and disorder that ripple out in shockwaves through Earth’s delicately balanced ecosystems” (Slade, 2022). Until recently, outdoor lighting was only seen as an indirect contributor to climate change and sustainability goals, but recent studies link them more directly (Zielinska-Dabkowska, 2022). “Light pollution is a generic term that groups all adverse effects generated by artificial lighting" (Tavares et al., 2021). Namely, these effects include environmental, wildlife, and human health impacts.

Human Health

Artificial lighting at night has a negative impact on both physical and mental health, in a variety of different ways. Extensive research has revealed that light has a significant impact on human physiology, endocrinology, and behavior (Lockley, 2009). Additionally, color temperature and brightness further impact human health.

Physical Health

Circadian rhythm is affected by both brightness and color temperature of lighting which impacts physical, mental, hormonal, and behavioral changes in humans. (Ibrahim et al., 2023). Human bodies naturally respond to the presence of certain wavelengths of blue (UV) light which are emitted by the sun, artificial lighting, and digital device screens such as our phones, computers, and TVs (Ibrahim et al., 2023). When these wavelengths of blue light make it to the eyes, it interacts with light-sensitive photoreceptive retinal ganglion cells (ipRGCs) in our retinas. These cells play an important part in melatonin production and circadian rhythm. The artificial light with blue wavelengths can interfere with the role these cells have which can lead to corresponding health issues. At night, melatonin, the "biochemical signal of night", is supposed to be released, helping humans to fall asleep and stay asleep (Mizon, 2012). Therefore, exposure to blue light at night eventually leads to sleep-related short and long-term health issues (Ibrahim et al., 2023).

Modern exterior light fixtures, namely LED sources, emit more blue light than the previous gas, kerosene, and incandescent lamps. Street lighting is utilized to illuminate roadways and objects below the light source, but poor design can lead to significant amounts of light being directed upward or outward instead of straight down (Gaston et al., 2012). Furthermore, commercial and architectural lighting may be designed to emit light at a horizontal or vertical angle, to better illuminate the object of focus (Gaston et al., 2012). These outdoor fixtures shine into adjacent windows via light trespass, impacting those living nearby. This light trespass commonly occurs when exterior lights illuminate upward and into bedrooms (Grose, 2015). Light trespass is the encroachment of light, typically across property boundaries, causing annoyance, loss of privacy, or other nuisance.

Furthermore, this outdoor lighting can also have other negative health impacts. Endocrine disruption is thought to largely affect these negative health issues, because light is the principal environmental cue in synchronizing circadian rhythm. Circadian dysregulation has widespread neuroendocrinological impacts on the production, signaling, and function of melatonin, as well as resistance to cancer (Stanhope et al., 2021). Additionally, many different aspects of sleep are also impacted by lighting. "Insomnia, sleep disorders and disturbances of deep sleep are induced by ALAN exposure. These outcomes may result in other, more chronic, health effects" (Cho et al., 2015). Cancer has also been linked to outdoor lighting, specifically breast and colorectal cancers (Pauley, 2004).

Mental Health

In addition to physical health implications, artificial lighting also has mental health effects (Slade, 2022). It has been associated with mood disorders, anxiety disorder, bipolar disorder, social phobia, and depression (Stanhope et al., 2021). These mental health implications are further discussed below.

One of the first studies to investigate associations between artificial nighttime lighting and mental disorders among adolescents in the United States reported connections between sleep patterns and mental disorders (Paksarian et al., 2020). This study analyzed associations with both "broad disorder classes, as well as individual disorders" (Paksarian et al., 2020). Some of the reported associations included bipolar disorder, major depressive disorder, and anxiety disorders (Paksarian et al., 2020). Similarly, a study in South Korea investigated the association of outdoor lighting specifically with depressive symptoms and suicidal behavior (Min et al., 2018). Substantial relationships were seen between outdoor lighting and the likelihood of depressive symptoms (Min et al., 2018).

<u>Color Temperature and Brightness</u>

Color temperature and brightness has a significant impact on exterior lighting design and human health. "Setting the ideal lumen output and color temperature for a space is critical when it comes to the regulation of our circadian rhythms, which has a significant impact on our health" (Ibrahim et al., 2023). Ideal lumen and correlated color temperature (CCT) levels vary by time of day but there are still standard methods that determine the ideal ranges. One such method is the Kruithof curve which is the result of a study from the early 1940's that concluded that conditions of lighting within a set region of the curve are viewed as comfortable whereas conditions outside of this set region are viewed as uncomfortable or harsh (Ibrahim et al., 2023).

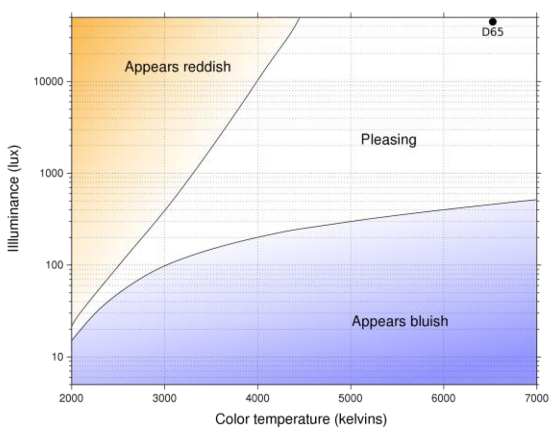

Figure 3 - Kruithof curve (Ibrahim et al., 2023).

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As is shown above in Figure 3, warm-toned sources appear red, and cool-toned sources appear blue. The goal for designers is to pick a source in the center white portion labeled ‘pleasing’ for optimum human comfort and satisfaction. Furthermore, there are certain CCT levels that are commonly used with specific intent to promote health, comfort, and productivity. These values are shown below in Figure 4. “In general, they are: 2700k to 3500k - warm lighting for residential, hospitality, and other relaxing environments, 3500k to 4000k - cool lighting for office and commercial spaces, 4000k to 5000k - daylight for industrial and manufacturing applications” (Ibrahim et al., 2023). These color temperatures don’t directly correlate to exterior use but do provide a better understanding of each of these temperatures. Exterior lighting CCT recommendations are detailed below.

Figure 4 - Color temperature (IES, 2020a).

Reprinted from ANSI/IES LP-2-20, Lighting Practice: Designing Quality Lighting for People in Outdoor Environments. New York: Illuminating Engineering Society, 2020).

Similar to concerns of physical and mental health impacts due to cool toned indoor lighting, exterior lighting color temperature also raises concerns. The American Medical Association (AMA) released a report in 2016 discussing the effects of LED lighting (and specifically street lighting) on human and environmental health (Kraus, 2016). This report included a recommendation to only use light sources with a CCT of less than 3000K. The Illuminating Engineering Society (IES) did not agree with the conclusions and recommendations of the AMA. Particularly, the IES asserted that CCT was not an adequate evaluation of possible health effects and that the recommendations only focused on the spectral composition of multi-variable characteristics of lighting (IES, 2017). More recently, IES still avoids recommending specific CCT values but does recommend using lower CCT values when possible (IES, 2022a). This correlates to the recommendations from Figure 3, in that there is a ideal middle ground where sources are not to cool but also not too cool.

Environmental

The effect of artificial lighting at night on the environment is also having lasting effects on climate change and flora which is in turn impacting the wildlife living in affected environments. These lasting effects can crucially damage ecosystems and lately, conservationists have taken particular notice (Mizon, 2012).

Plants are constantly exposed to biological and physical signals from their surroundings. They have evolved to effectively detect and react to these many signals. Additionally, plants greatly rely on these signals for growth and development. Among the most impactful signals are those originating from the "light environment" (Rich et al., 2006). "Artificial lighting can significantly disrupt the natural light/dark patterns" (Mizon, 2012). Plants have different growth reactions in the dark with a focus on stem growth and height, than in the light with a focus on leaf growth and budding. "Among the many processes affected by light are seed germination, stem elongation, leaf expansion, conversion from a vegetative state to a flowering state, flower development, fruit development, cessation of leaf production (bud dormancy), and leaf senescence and abscission" (Rich et al., 2006).

The plant's photoreceptors enable it to react to four aspects of the light environment: the quality, intensity, direction, and duration of light. "Sometimes these photoreceptors act independently, sometimes redundantly, sometimes cooperatively, sometimes antagonistically, sometimes at the same stage of development, sometimes at different stages of development"

(Rich et al., 2006). Furthermore, certain responses perceive light levels almost imperceptible to the eye, while others respond only under high-intensity light conditions.

Outdoor lighting in the evening affects more than just the photoreceptors and growth of plants. Outdoor illumination directly impacts climate change in urban areas by causing “spring seasons [to commence] earlier as the photoperiod of illuminated trees and plants is extended and their leaves bud prematurely” (Zielinska-Dabkowska, 2022). Similar impacts occur again in the winter when these trees and plants don’t lose their leaves on time, causing them to become weaker and unhealthy which makes them an easy target for flooding and pests. Moreover, plants use evenings to regenerate and repair cells that were damaged throughout the day. Artificial lighting found in urban environments interrupts this process.

Different types of plants obviously have different responses to artificial night lighting, however, it is clear that most plant species have some sort of response. “Without a doubt artificial lighting affects plants” (Rich et al., 2006). The health of flora is important because they play crucial roles in urban settings by counteracting air pollution, reducing noise, and lowering temperatures caused by excess hardscapes and concentrated human activities (Salmond et al., 2016). Furthermore, plants create the ecosystems in which various animals such as birds, insects, and bats live (Zielinska-Dabkowska, 2022).

Wildlife

Artificial lighting at night also has direct and indirect effects on native wildlife. Travel patterns of birds and other migratory animals are impacted, activity patterns of sea life are altered, and nocturnal animals are in danger of excessive predation. “Ambient light influences the reproductive physiology, migration, foraging, and hence the parental behavior of many species" (Rich et al., 2006). Among wildlife impacted by light pollution are mammals, birds, and sea life.

Mammals

Artificial lighting at night can conceal the natural signals that sunlight triggers as well as alter predator risks both real and perceived for mammals (Hoffmann, 2021). "Small prey species may be particularly susceptible to ALAN as it makes them more conspicuous and thus more vulnerable to predation by visually oriented predators" (Shier et al., 2020). This additional unnatural exposure to lighting puts these prey species in unnecessary danger and gives the predators an abnormal advantage.

Furthermore, outdoor lighting can have unwanted impacts on mammal activity and behavior. "A large portion of mammals are active primarily at night, and ALAN is very likely to affect them given that mammalian evolution was likely driven by adaptations for nighttime activity" (Shier et al., 2020). These nocturnal mammals are highly influenced by the moon and the cycles associated with it. These lunar cycles create natural fluctuations in ambient light levels that are distinctly different from the continual illumination provided by artificial lighting. These changes in illumination have significant impacts on activity levels and foraging. For example, small nocturnal mammals are less likely to forage in artificially lit environments. This is partly due to a perceived predation risk and partly due to temporary blindness that these small animals experience due to the physical properties of their eyes (Shier et al., 2020). The disruption from the natural conditions caused by outdoor lighting clearly impacts these species.

Birds

Many species of birds are impacted by the effects of excessive artificial lighting. "Perhaps more than any other vertebrates, birds are intimately and inextricably linked with the light features of their environments" (Rich et al., 2006). A large portion of species of birds migrate at night. During this nighttime migration, artificial light sources can severely alter their course and confuse these species. "All evidence indicates that the increasing use of artificial light at night is having an adverse effect on populations of birds, particularly those that typically migrate at night" (Rich et al., 2006).

It is becoming increasingly clear that birds are being attracted to artificial light. "It is well known that fires and artificial lights attract birds during migration" (Rich et al., 2006). This instinctive attraction to light, regardless of whether it is natural or artificial, has deadly consequences for these birds. Two main outcomes result from this innate attraction to light sources, the first being mass collisions and the second being a so-called trapping effect.

Collisions with illuminated buildings and other structures are the result of potential blindness or general confusion caused by flying towards artificial light sources. High numbers of bird deaths are reported from collisions with buildings. "An estimated 365 million to 988 million birds die in collisions with buildings annually, according to Cornell University's BirdCast program, which urges cities and other building owners to extinguish or dim outdoor lighting during fall and spring migration" (Halfpenny, 2023). Reports of these large numbers of collisions include hundreds in one night in New York City, 1000 to 1500 in one night in Philadelphia, and 400 collisions with a single building in Galveston (Halfpenny, 2023). A study consisting of multiple buildings in Minnesota found that while bird collisions with buildings occur primarily near glass surfaces, they occur in higher numbers in areas where the glass is emitting ALAN (Lao, 2020). While this isn't exterior lighting, it does show that illumination impacting the night sky has an impact on birds.

On the other hand, a lot of the issues associated with outdoor lighting and birds are more indirect and therefore hard to identify. Several of these indirect issues are related to light source trapping. The birds are attracted to the artificial light source and then get confused into circling or flocking to these sources for hours or even days. “This holding or trapping effect of intense light can deplete the energy reserves of migrating birds, rendering them incapable of making it to nearest landfalls” (Rich et al., 2006). These birds may fall into the water or land tired and weak on platforms (Rich et al., 2006) becoming easy prey (Halfpenny, 2023) or collide with other birds or nearby buildings (Hufnagel, 2022).

Sea Life

About a quarter of humans live within roughly 60 miles of coastlines (Bassi et al., 2021) contributing to outdoor lighting near oceans. Artificial lighting near water can have exacerbated skyglow effects. Light that is emitted near coastlines can expand out toward the waters and scatter along the surface causing issues with reflections and glare, directly impacting animals living in or near the water.

One of the most notable impacted animals are sea turtles. Outdoor lighting severely disrupts the migration of sea turtle hatchlings on the path to the ocean. These hatchlings innately know to follow the light of the moon and the reflection from the ocean, but artificial light confuses these young animals. The artificial light can blind, distract, or disorient the hatchlings on their sea-finding journey (Hufnagel, 2022). “Instead of tracks leading directly to the sea, turtles leave evidence that they crawled for hours on circuitous paths (‘disorientation’), or on direct paths away from the ocean and toward lighting (‘misorientation’)” (Salmon, 2003). Thousands of hatchlings die each year due to exhaustion, predators, dehydration, or even incorrect human intervention. Additionally, adult female sea turtles preparing to lay eggs can be affected in similar ways by nearby artificial lighting. At a minimum, lights from urbanization along the coasts deter the nesting sea turtles, sometimes leaving the adult females without an ideal nesting location.

Although the analysis and research surrounding lighting and fish is fairly limited, there is evidence that they are directly and indirectly impacted by outdoor lighting. Artificial light at night can influence the activity, health, behavior, and predation of fish (Bassi et al., 2021). Evidence shows that light pollution is associated with swimming activity which could lead to further issues with energetic demand (Bassi et al., 2021). When certain species of fish are exposed to light, they are more active, typically due to working against currents in order to remain in lit areas. Fish quickly tire as a result of this increased activity. Additionally, similar to other animals and humans, circadian rhythm has significant impacts on fish (Tavares et al., 2021).

Review of Design Documents

Industry standards, codes, and guidelines play an important role in ensuring sustainable and high quality outdoor lighting practices. They provide a framework for designing lighting systems that minimize environmental impact and energy consumption while maximizing efficiency and safety. While these documents all tend to have similar goals, they each offer unique perspectives with different opportunities for design impact.

Codes are required and enforceable once accepted by a jurisdiction. Standards establish minimum acceptable levels of quality or performance and can be referenced within or adopted as code. Guidelines are general recommendations or best practices typically developed by subject matter experts. When these documents offer differing advice, meeting mandatory code requirements will always be the first priority. However, progressive code adaptation regarding light pollution should be a priority. Trying to meet a majority of applicable recommendations that these documents provide typically provides the most impact on a project.

By adhering to established standards, manufacturers and designers can contribute to the reduction of light pollution. Sustainable outdoor lighting standards also promote the use of emerging energy-efficient technologies, which continually pushes the industry toward more advanced standards of practice. As the importance of environmental conservation and energy efficiency continues to grow, industry standards serve as a crucial tool for guiding responsible practices in outdoor lighting, ultimately contributing to a more sustainable and resilient future. These standards are not required, however utilizing these recommendations are vital to seeing improvement in this global issue.

IES Documents

Documents from IES, like those below, are guidelines as opposed to codes or standards. These guidelines are prepared by committees of experts within the industry and provide comprehensive direction of many different applications. IES has a very large collection of guidelines and documents and many of these documents were not included in this review of design documents. The guidelines that are most applicable to the research and discussion of this report were chosen to be reviewed and detailed. That is not to say that other guidelines could not also be applicable, but rather that these were the most applicable of the published documents at the time this report was written. Most notably, all current IES guidelines regarding exterior lighting were included.

Two kinds of documents from IES are included in this review of documents: Recommended Practice (RP) and Lighting Practice (LP). Recommended Practice documents include detailed design criteria for many applications (commercial, residential, industrial, etc.) and also include recommended illuminance criteria to guide the design process using comprehensive tables. Lighting Practice documents include basic interior and exterior design principles involving light sources, fixtures, and controls.

<u>RP-43-22: Recommended Practice: Lighting Exterior Applications</u>

RP-43-22 is the first document included in this review of IES documents. This document is the recommended practice for exterior applications. It details the illuminance criteria and recommendations for all exterior applications. This is a very detailed and comprehensive document with several helpful tables and figures, as discussed below.

Lighting for the outdoor environment is different from interior lighting. It can be difficult to decide where or how much to illuminate an area. “When the need for darkness conflicts with a desire or need for light, good lighting design finds a workable balance between nighttime use and concerns related to human health, aesthetics, and environmental impact" (IES, 2022a). RP-43-22 provides guidance in finding this balance. One of the main concerns RP-43-22 addresses is lighting systems that over-illuminate pedestrian tasks. Recommendations on where, when, and how much light to use are specific to site types, but the general recommendation is to provide the minimum amount of light necessary.

Instead of only focusing on illuminance, this recommended practice also considers lighting zones, glare, color, and other visual conditions. This guideline also defined the adopted five principles for responsible outdoor lighting that was introduced earlier in this report These principles are key for well designed outdoor lighting.

Glare is a significant consideration in exterior lighting design. High levels of illumination coming directly from fixtures and high contrast in illumination between surfaces within view may reduce visibility which creates a safety hazard (IES, 2022a). There are three types of glare that this document addresses: disability glare, discomfort glare, and nuisance glare. Disability glare is a reduction in visibility occurring from a bright source of light close to the eye, which then scatters within the eye, reducing contrast. Discomfort glare causes a physical pain or aversion response but may or may not reduce task visibility. This kind of glare can occur from any bright light source in view, or even slightly outside of view, as opposed to only sources close to the eye. Nuisance glare is distracting, unnecessary, or unwanted light.

Adaptation from high illumination to low illumination areas can have significant impacts on safety. "Transitions from a brightly illuminated or very dark environment to one of very different luminance will cause a transitional loss of visual acuity, and this effect grows worse with age" (IES, 2022a). RP-43-22 emphasizes that quality design involving light should create smooth transitions between these contrasting illuminations. Furthermore, this document highlights the importance of selecting luminaires that are closer to pedestrian height and shielded to avoid glare.

RP-43-22 also discusses specific outdoor lighting applications and considerations for their design. This recommended practice asserts that safety and security are crucial for exterior lighting design. "Lighting for safety involves ensuring proper level of illumination to identify hazards or obstructions, with low-glare lighting to allow for better adaptation, which will help provide safe working conditions and safe passage" (IES, 2022a). Security focused lighting is installed to increase the impression of safety and to aid protection from criminal activity. "The security of people and property involves psychology, perception, and other issues" (IES, 2022a). Thus, this guideline asserts that it is a much more difficult task than lighting only for safety. This document also asserts that security lighting should not be an afterthought, but rather be a fully integrated part of a complete security system. Lighting alone is not sufficient to provide security. This document also specifically notes that increasing illumination does not inevitably improve security. "With consideration and use of modern equipment, it is usually possible to find a balance between adequate security and the desire for non-polluting light" (IES, 2022a). It is common to assume that lighting that is continually on is required for effective security lighting, but static lighting may actually cause a feeling of complacency or lack of attention to the area. Using motion sensing to change illumination levels can focus attention on the area. "Using lighting controlled by motion sensors or similar devices that turn lighting on when a potential threat is detected can increase security" (IES, 2022a). Whether these devices go from full off to full on or to flashing on or something similar, this change in illuminance will draw attention to the area. These devices can also be tied into notification systems that can send alerts to the building owner, security staff, or building management staff. This topic is further discussed in the Basic Needs for Outdoor Lighting section of this report.

RP-43-22 includes an extensive multi-page table (Table A-3) that details recommended illuminance criteria for outdoor environments. This table is not included in this report but can be found in RP-43-22. This table is broken into different applications and split into different lighting zones for each application. Furthermore, there is a listed upper and lower target illuminance for each lighting zone.

IES lighting zones (LZ) range from 0 to 4. The most conservative of the lighting zones, LZ-0: no ambient light, is expected to have no artificial lighting (such as natural parks). In the next lighting zone, LZ-1: low ambient light, non-continuous, lighting at low levels is used where needed. In areas categorized as LZ-2: moderate ambient light, there is a more moderate expectation of artificial lighting. In LZ-3: moderately high ambient light, more continuous artificial light is utilized. In areas with high levels of human activity at night, LZ-4: high ambient light is used, with higher illumination levels.

To aid in the use of the illuminance table, IES also provides Table 1 (Table A-1 in RP-43-22) for additional guidance in selecting target illuminances. There are many reasons why a lighting professional might decide to target the high, middle, or low values of the range. It is appropriate to increase or decrease illumination within that range as long as the reasons are documented for the project (IES, 2022a). This table "provides weighting factors to assist the lighting professional" (IES, 2022a). These weighting factors include usage levels, seasonal changes, preferences or expectations of the client or occupant, safety, glare, and age of the occupant.

For areas or applications that indicate the need for a variance from the target illuminations, the applicable weighting factors are totaled, as shown in Table 2 (Table A-2 in RP-43-22). If this sum totals four or more, then it would be appropriate to target the high end of the illuminance range. Similarly, it would be appropriate to target the low end of the illuminance range if the sum totals negative four or less. Targeting the middle of the range occurs with scores totaling between negative three and three. “It is important for lighting professionals to document variances from recommended light levels; [Table 1] can be used as a documentation method” (IES, 2022a). By circling where the project lies on each row, the designer can document the total weighting factors for the project.

Table 1 - Weighting factors for selecting target illuminance (IES, 2022a). Reprinted from ANSI/IES RP-43-22, *Recommended Practice: Lighting Exterior Applications* New York: Illuminating Engineering Society, 2022.

Table A-1. Weighting Factors for Selecting Target Illuminance

Weighting Factors for Variance from Target Illuminance	Reduces Need for Light (-1)	No Impact on Need (0)	Increases Need for Light (+1)
Usage levels	Low usage	Normal usage	High usage
Path priorities	Tertiary	Secondary	Primary
Seasonal changes	Winter snow		
Adjacencies	"Borrowed" light, glare concerns, or light unwanted	Neutral	Light wanted to improve perception of safety and activity; older pedestrians are a critical population
Client preferences; social settings; cultural expectations	Wants less light or prefers less uniformity	Neutral	Wants more light or prefers higher uniformity
Pavement condition	No level variation, high quality surface		Rough, uneven surface
Hazards or obstacles; wayfinding	Curbs, level changes, stairs, or obstacles have finishes that enhance contrast; or, retroreflective materials are used to create contrast		Level changes, tripping hazards, and obstacles do not use high-contrast materials
Mixed travel types			Bicycles, skateboards, or other non-motorized vehicles in addition to foot traffic
Safety; visibility of pedestrians	Subordinate to environmental issues	Neutral	Enhanced safety and/or visibility required
Glare from luminaires	Reduced glare for pedestrians, allowing clear visibility of pavement, objects, and surrounds		Higher glare for pedestrians, necessitating a higher ambient light level
Age of users	Users and supervisors predominantly less than 25 years old	Broad range of user ages	Users predominantly over 60 years old

In addition to Table 1, the IES also includes Table 2 (Table A-2 in RP-43-22) as an example to show how to use and apply the weighting factors of Table 1 and sum the results. As shown, the provided example from IES sums to negative three, so it is likely the designer would target the mid-range of illuminance recommendations from Table A-3 (which again is not included in this report). For example, façade lighting in Table A-3 for LZ-3 has a recommended illuminance 0.4-3 fc. So, the designer would target the middle of this range which would likely be roughly 1.7 fc.

Table 2 - Weighting factors (IES, 2022a).

Reprinted from ANSI/IES RP-43-22, *Recommended Practice: Lighting Exterior Applications* New York: Illuminating Engineering Society, 2022.

Table A-2. Weighting Factors for This Example

Weighting Factor	Score
Usage levels	0
Path priorities	0
Seasonal changes	0
Adjacencies	-1
Client preferences and cultural expectations	-1
Pavement condition	+1
Hazards or obstacles, and wayfinding	0
Mixed travel types	0
Safety and visibility of pedestrians	-1
Glare from luminaires	-1
Age of users	0
TOTAL	**-3**

LP-2-20: Lighting Practice: Designing Quality Lighting for People in Outdoor Environments

The next document included in this review is LP-2-20 which describes how to design quality lighting for outdoor environments with an emphasis on people. This document was included because most outdoor lighting applications have some sort of pedestrian component. LP-2-20 walks through the design process of pedestrian focused exterior lighting.

Even though a number of IES standards provide recommendations and guidelines for specific outdoor applications, LP-2-20 is not intended to replace or override those documents. Rather, it supports and adds to those documents. Specifically, this lighting practice document focuses on the importance of lighting design for pedestrian-based tasks. Lighting recommendations for exteriors were historically made from a vehicular perspective instead of a pedestrian perspective. The role of vehicular lighting is for motorists to see potential obstacles associated with viewing angle and movement. Not only are the needs of a lighted environment completely different for motorists than for pedestrians, but pedestrians are also more vulnerable than motorists. Thus, this document asserts that there should be a reduction in "vehicular roadway-centric lighting" as the primary solution for exterior lighting design (IES, 2020a). Many interior lighting strategies like light layering can now also be applied to exterior applications.

Light layering is the use of multiple lighting systems to create a balanced and functional design. Using a combination of ambient, task, accent, and decorative lighting creates an optimal design. In an exterior application, ambient lighting may refer to parking or street lighting, task lighting may be pedestrian focused lighting, accent lighting could refer to façade or landscape lighting, and decorative lighting may include additional lighting that is simply for aesthetics such as colored lighting.

This lighting practice document also helps lighting designers gain a more holistic understanding of the aspects that affect exterior spaces. These influential aspects include ambient lighting levels, glare, contrast, and luminance. This document has a specific focus on how lighting design affects pedestrians and pedestrian oriented spaces. "These recommendations provide a basis for lighting and space design, including the flexibility for application of multiple methods" (IES, 2020a). A pedestrian is typically defined as someone who travels on foot. This document infers that pedestrians move at a slower speed than vehicles. This document analyzes a number of different "fundamental considerations for pedestrian lighting" including wayfinding, reassurance, safety, atmosphere, human health, environmental impact, and location. Additionally, similar to RP-43, this document discusses glare, light level, adaptation, uniformity, and color. This lighting practice also has an entire section detailing the design process specifically for these applications with pedestrian spaces.

Lighting design challenges pertaining to outdoor lighting can vary widely. LP-2-20 asserts that these issues include context, location, intended use, design, and user expectation (IES, 2020a). Despite this variation, there are several fundamental principles that aid in the successful illumination of these pedestrian environments. “Quality outdoor lighting should communicate visual order, hierarchy, and spatial character” (IES, 2020a). LP-2-20 presents Figure 5 to visually provide a foundation for this hierarchy which guides quality lighting for people in exterior environments. “Lighting designs should respect and relate to the principles, ideas, and intended hierarchical relationships of the visual environment” (IES, 2020a). Some of these principles include orientation/wayfinding, reassurance, facial recognition, pedestrian safety, and atmosphere/enjoyment. The document details these principles in greater detail than is included in this review.

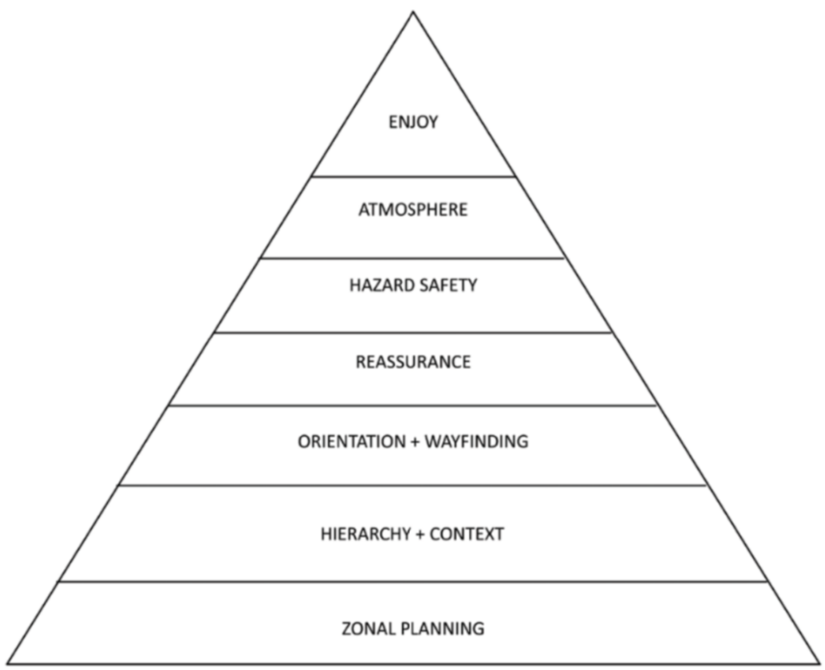

Figure 5 - Hierarchal process of designing quality lighting for people in outdoor environments (IES, 2020a).

Used with permission of Landscape Forms.

<u>LP-6-20: Lighting Practice: Lighting Control Systems – Properties, Selection, and Specification</u>

Additionally, LP-6-20 is included in this review. This Lighting Practice focuses on lighting control systems. While this document isn’t only focused on exterior lighting controls, it is a good overview of some of the recommendations that IES provides on a broader scale.

Recently, with an increase in sustainability discussions and stricter energy codes, automatic lighting controls have become more widely used in building lighting design. While this document focuses on interior applications, the same principles can be utilized and implemented in outdoor design as well. “These devices and systems automatically switch or dim designated loads in response to events such as time of day, daylight fluctuation, occupancy, or energy-demand reduction events” (IES, 2020b). One of the current energy standards in the U.S., ANSI/ASHRAE/IES Standard 90.1-2022 (discussed in the codes section of this review of design documents), details mandatory control requirements to conform with minimum design practices, whereas LP-6-20 discusses additional optional controls practices.

LP-6-20 “is intended to help designers, users, commissioning providers, and other interested parties understand fundamental characteristics and purposes of lighting control systems” (IES, 2020b). This document discusses many design considerations including owner project requirements, economic considerations, building codes, maintenance, user expectations, control zoning, energy codes, integration, and dimming. This document also analyzes specific control strategies available to lighting designers including basic methods, personal tuning, institutional tuning, adaptation compensation, occupancy and vacancy sensing, time scheduling, daylight harvesting, lumen maintenance dimming, demand response, shade control, scene control, emergency lighting control, color mixing, and tunable white. Further controlling light sources is also discussed in depth. Specific methods and protocols, equipment, and design deliverables are detailed as well.

Table 3 lists some control methods as well as their applications. Furthermore, this table includes additional comments about each listed control method. These comments can be used to compare aspects of the control methods such as flexibility, expense, specific uses, occupant use, energy savings, and difficulty of implementation.

Table 3 - Lighting control options and applications (IES, 2020b).

Reprinted from ANSI/IES LP-6-20, *Lighting Practice: Lighting Control Systems – Properties, Selection and Specification*. New York: Illuminating Engineering Society, 2020.

Table 4.1. Lighting Control Options and Applications

Control Method	Application	Comments
On/off	When lighting for a space or control zone will be used at the off and full output settings only	• Provides occupant with control • Inexpensive • May not comply with energy in some applications
Dimming (manual or automatic)	When a range of light levels is desired from individual luminaires	• Flexible • The lighting system can be tailored to the needs of the space and occupants • More expensive than switching • Not all sources are dimmable
Scene control	When users of a space will benefit from access to different preset lighting scenes, such as when multiple lighting zones are being dimmed	• Convenient & simple for user • Flexible, adapts lighting to space functions • Discrete spaces may need to serve multiple functions • Supports response to various preprogrammed occupancy states
Photosensor dimming	When incident daylight is present in sufficient quantities to serve as the primary source of light for a space or an area within a space	• Control and energy savings in response to daylight is automatic • Light level changes should be unnoticeable • Requires proper lighting system layout and programming
Photosensor (photocell) switching	When daylight is present in sufficient quantities to permit a lighting control zone to be turned off completely a large fraction of the time, and a sudden reduction in electric light output is acceptable	• Less expensive than photosensor dimming • Occupants may object to the abrupt light level changes resulting from automatic switching systems in most work spaces • Requires proper lighting system layout and programming
Occupancy control	When lighting is likely to remain on when the space is vacated	• Potential energy savings are significant • Energy codes may require vacancy sensing (manual-on/automatic-off)
Time control	When repeatable patterns of space use make time of day scheduling desirable	• Control of the lighting system is automatic for expected periods of occupancy • Lighting levels may be lowered for less critical functions, such as space cleaning and retail space restocking • System override actions are required • Multiple shutoff times should be provided to turn lighting off following system overrides

LP-10-20: Lighting Practice: Sustainable Lighting – An Introduction to the Environmental Impacts of Lighting

The next document included in this review is LP-10-20. This document is a Lighting Practice specifically for sustainable lighting and environmental impacts. This document is thus quite applicable to the topic of this report. This document includes a section introducing sustainable definitions, an overarching section on sustainable design, a section detailing sustainable lighting elements, and a summary section. This lighting practice document can be read from start to finish as a document on sustainable lighting or referenced by section for specific topical direction. This document is not designed to be an all-inclusive text on lighting sustainability seeing as that is such a broad topic to cover in a single document. Thus, this document should be utilized as a general guide that discusses the aspects that need to be reviewed when designing sustainable lighting not as a “how-to guide”.

LP-10-20 utilizes the definition from the IES and the International Association of Lighting Designers (IALD) of sustainable lighting design. “Meeting the qualitative needs of the visual environment with the least impact on the natural environment” (IES, 2020c). This document details the environmental impacts of lighting. “Visually effective and appealing, high-quality lighting provides the greatest environmental and economic value” (IES, 2020c). The purpose of this document is to present the subject of sustainability, discuss its components, and analyze its impacts on lighting design. Since energy concerns are so influential in lighting, many lighting design professionals only correlate environmental effects with energy consumption, when there are actually many other factors.

LP-11-20: Lighting Practice: Environmental Considerations for Outdoor Lighting

The last Lighting Practice included in this review is LP-11-20, which introduces environmental considerations related to exterior lighting. This document is closely related to LP-10-20, but it places extra emphasis on the consideration of environmental impacts caused by exterior lighting. It asserts that the environmental effects should always be reviewed when designing outdoor lighting. “While exterior lighting may be necessary for mobility, the feeling of safety, and commerce, used indiscriminately, the light pollution produced by it reduces the enjoyment of the natural nighttime sky, and may create biodiversity issues” (IES, 2020d). This document specifically details the environmental concerns of outdoor lighting particularly with respect to glare, sky glow, light trespass, and artificial lighting effects on plants and animals. Effects on human health, animals, and plants are detailed extensively. How these effects can be best minimized is also discussed in detail. There is an entire section on lighting zones. Furthermore, there is also a section on developing an effective lighting ordinance to control the quality of exterior lighting and an additional section specifically focused on lit exterior signage.

Review of Codes & Standards

As discussed previously, codes and standards play an important role in sustainable exterior lighting design. These documents provide the minimum required levels of acceptable design for the industry which frame the limitations designers have with respect to exterior lighting. They have similar goals to those of guidelines; however, they are more enforceable.

International Energy Conservation Code (IECC) - 2021

Codes are enforceable by local jurisdictions and minimums of acceptable design. One such code relating to sustainable exterior lighting design is the IECC. This code addresses energy efficiency and details the requirements that must be met in order to be code compliant. The following section details the specifics of the 2021 edition of this code. Not all jurisdictions have adopted this newest edition as law, but it does give a good indication of the direction the industry is going. Furthermore, even when not required, these additions to code tend to be worth following when applicable and reasonable. It is important to utilize applicable recommendations from codes, standards, and guidelines whenever feasible.

Section C405 of the IECC is devoted to electrical power and lighting systems. Section C405.2.7 details the exterior lighting controls requirements (International, 2021). The first lighting control requirement that is introduced is daylight shutoff. This requirement states lighting must be automatically turned off once daylight is present and satisfactory (International, 2021). As soon as the lighting needs are met, lights shall be automatically turned off. The building facade and landscaping requirement states that this lighting be automatically shut off within an hour after closing to within an hour of opening (International, 2021). The third control requirement introduced is lighting setback which has two options for non-facade or landscape lighting. The first is that the total wattage be reduced to at least 50% by selectively turning off fixtures or dimming them from at least midnight to 6 a.m., or within an hour of closing to within an hour of opening, or during any time where motion isn't detected for at least fifteen minutes (International, 2021). The second is for outdoor parking areas with fixtures that are more than 78 watts each and have fixture mounting heights of 24 feet or less. The total wattage consumed for this lighting should be automatically reduced to at least 50% any time motion is not detected for fifteen minutes or more (International, 2021). The next control requirement, exterior time-switch control function, shall have a clock with at least a seven unique days programming capability, shall incorporate an automatic holiday setback, and have backup capabilities (International, 2021).

Section C405.5 discusses exterior lighting power requirements. The total exterior connected lighting power is stated to be the total maximum wattage of all exterior lighting being powered through the building service (International, 2021). There are a number of exceptions to this statement, which are listed below C405.5.1. The exterior lighting power allowance is calculated according to C405.5.2. The lighting zone is first determined using Table 4 (Table C405.5.2(1) in IECC-2021). The applicable area type is then determined via Table 5 (Table C405.5.2(2) in IECC-2021) using the most similar area to that of the proposed use. Then, the total area or length of each area type is found and multiplied by the area type value in the same table, Table 5 in order to find the allowed lighting power for each area type. Finally, the sum of the base site allowance plus the watts from each area type is calculated, resulting in the total exterior lighting power allowance.

Table 4 - Exterior lighting zones (1) (International, 2021).

TABLE C405.5.2(1) EXTERIOR LIGHTING ZONES

LIGHTING ZONE	DESCRIPTION
1	Developed areas of national parks, state parks, forest land, and rural areas
2	Areas predominantly consisting of residential zoning, neighborhood business districts, light industrial with limited nighttime use and residential mixed-use areas
3	All other areas not classified as lighting zone 1, 2 or 4
4	High-activity commercial districts in major metropolitan areas as designated by the local land use planning authority

Table 5 - Lighting power allowances for building exteriors (International, 2021).

TABLE C405.5.2(2) LIGHTING POWER ALLOWANCES FOR BUILDING EXTERIORS

	LIGHTING ZONES			
	Zone 1	Zone 2	Zone 3	Zone 4
Base Site Allowance	350 W	400 W	500 W	900 W
Uncovered Parking Areas				
Parking areas and drives	0.03 W/ft^2	0.04 W/ft^2	0.06 W/ft^2	0.08 W/ft^2
Building Grounds				
Walkways and ramps less than 10 feet wide	0.50 W/linear foot	0.50 W/linear foot	0.60 W/linear foot	0.70 W/linear foot
Walkways and ramps 10 feet wide or greater, plaza areas, special feature areas	0.10 W/ft^2	0.10 W/ft^2	0.11 W/ft^2	0.14 W/ft^2
Dining areas	0.65 W/ft^2	0.65 W/ft^2	0.75 W/ft^2	0.95 W/ft^2
Stairways	0.60 W/ft^2	0.70 W/ft^2	0.70 W/ft^2	0.70 W/ft^2
Pedestrian tunnels	0.12 W/ft^2	0.12 W/ft^2	0.14 W/ft^2	0.21 W/ft^2
Landscaping	0.03 W/ft^2	0.04 W/ft^2	0.04 W/ft^2	0.04 W/ft^2
Building Entrances and Exits				
Pedestrian and vehicular entrances and exits	14 W/linear foot of opening	14 W/linear foot of opening	21 W/linear foot of opening	21 W/linear foot of opening
Entry canopies	0.20 W/ft^2	0.25 W/ft^2	0.40 W/ft^2	0.40 W/ft^2
Loading docks	0.35 W/ft^2	0.35 W/ft^2	0.35 W/ft^2	0.35 W/ft^2
Sales Canopies				
Free-standing and attached	0.40 W/ft^2	0.40 W/ft^2	0.60 W/ft^2	0.70 W/ft^2
Outdoor Sales				
Open areas (including vehicle sales lots)	0.20 W/ft^2	0.20 W/ft^2	0.35 W/ft^2	0.50 W/ft^2
Street frontage for vehicle sales lots in addition to "open area" allowance	No allowance	7 W/linear foot	7 W/linear foot	21 W/linear foot

Additional exterior lighting power allowances are available for use in specific lighting applications as listed in Table 6 (Table C405.5.2(3) in IECC-2021). These additional power allowances should not be used to increase any other lighting power allowance, but rather are to be utilized for the luminaires serving these specific applications (International, 2021).

Table 6 - Additional lighting power allowances (International, 2021).

TABLE C405.5.2(3) INDIVIDUAL LIGHTING POWER ALLOWANCES FOR BUILDING EXTERIORS

	LIGHTING ZONES			
	Zone 1	Zone 2	Zone 3	Zone 4
Building facades	No allowance	0.075 W/ft^2 of gross above-grade wall area	0.113 W/ft^2 of gross above-grade wall area	0.15 W/ft^2 of gross above-grade wall area
Automated teller machines (ATM) and night depositories	135 W per location plus 45 W per additional ATM per location			
Uncovered entrances and gatehouse inspection stations at guarded facilities	0.50 W/ft^2 of area			
Uncovered loading areas for law enforcement, fire, ambulance and other emergency service vehicles	0.35 W/ft^2 of area			
Drive-up windows and doors	200 W per drive through			
Parking near 24-hour retail entrances.	400 W per main entry			

ANSI/ASHRAE/IES Standard 90.1-2022 - Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings

As discussed previously, standards are similar to codes, they just don't usually have as much power until adopted into law. These documents are very beneficial guides to design, even when not adopted into code. ASHRAE Standard 90.1, an alternate compliance path to IECC, provides the minimum energy-efficient design requirements for buildings, except low-rise residential buildings (ASHRAE, 2022). "Standard 90.1 has been a benchmark for commercial building energy codes in the United States, and a key basis for codes and standards around the world, for almost half a century" (ASHRAE, 2022). This standard provides both minimum requirements and criteria for determining compliance with these requirements. This standard is a very helpful tool for designers, engineers, and other professionals.

Section 9 of ANSI/ASHRAE/IES Standard 90.1 is devoted to lighting, both interior and exterior, of a building and its site. Section 9.1 introduces the scope information for lighting. Section 9.2 describes the compliance path options for lighting. Section 9.3 presents the simplified building method compliance path. This section can be used for buildings where at least 80% of the floor area is utilized as office, retail, or school space. It can be used for new buildings or tenants improvements of less than 2322 m^2. For all building types listed in section 9.3, exterior areas should follow the lighting power allowance and control requirements of Table 7 (Table 9.3.2 in ASHRAE 90.1-2022). This table details different exterior area types, the corresponding exterior lighting power allowance, and the corresponding controls requirements.

Table 7 - Simplified building method for building exteriors (ASHRAE, 2022). ©ASHRAE, www.ashrae.org. (2022) ASHRAE Standard-90.1.

Table 9.3.2 Simplified Building Method for Building Exteriors

Exterior Area Type	Exterior Lighting Power Allowance [a,b]	Controls
All exterior areas		All lighting shall be *automatically* controlled to shut off the lighting when daylight is available.
Base allowance	200 W	*Luminaires* shall be turned off or the power reduced by a minimum of 75% during nonoperating hours.
Façade lighting	0.10 W/ft^2	*Luminaires* shall be turned off or the power reduced by a minimum of 75% during nonoperating hours.
Roof terraces, special feature areas, walkways, plazas and ramps	0.07 W/ft^2	*Luminaires* shall be turned off or the power reduced by a minimum of 75% during nonoperating hours.
Landscape	0.036 W/ft^2	*Luminaires* shall be turned off or the power reduced by a minimum of 75% during nonoperating hours.
Entry doors	14 W/linear ft	*Luminaires* shall be turned off or the power reduced by a minimum of 75% during nonoperating hours.
Stairs	Exempt	No additional controls required.
Parking lots and drives	0.037 W/ft^2	*Luminaires* mounted 25 ft or less above *grade* shall be controlled to reduce the power by at least 50% when no activity is detected for not longer than 15 minutes.
All other areas not listed	0.20 W/ft^2	*Luminaires* shall be turned off or the power reduced by a minimum of 75% during nonoperating hours.

a. To calculate the exterior allowance, multiply the *space* or area square footage by the allowed W/ft^2 and sum the exterior allowances and the base allowance. Façade lighting shall be calculated separately by multiplying the facade area by the allowed W/ft^2. Façade allowance shall not be traded with other exterior areas or between separate *facade areas*.
b. For *buildings* in Lighting Zone 2, as defined in Table 9.4.2-1, multiply exterior allowances by 0.7. For *buildings* in Lighting Zone 4, as defined in Table 9.4.2-1, multiply exterior allowances by 1.4.

Section 9.4 introduces mandatory provisions for lighting. Subsection 9.4.1.4 lists the exterior control requirements that are also indicated in Table A.1 (Table 9.4.2-2 in ASHRAE 90.1-2022). These requirements are listed below:

a) OFF control - one or more lighting control to turn off all lights in the area/surface.

b) Daylight OFF control - automatically turn off lighting with sufficient daylight or within 30 minutes of sunrise.

c) Scheduled OFF control - automatically turn off lighting between midnight or business closing (whichever is later) and six a.m. or business opening (whichever is first) or between times established by the authority having jurisdiction (AHJ).

d) Scheduled light reduction control - automatically reduce to 50% instead of full off, within the same times as c).

e) Occupancy-sensing light reduction control - controlled to automatically reduce by 50% when no activity has been detected by the controlled luminaires for a time of no longer than fifteen minutes. No more than 1500 W of lighting power shall be controlled together.

Section 9.4.2 details exterior lighting power requirements and conditions. The total exterior lighting power allowance is the sum of the base site allowance plus the individual allowances for the areas that are designed to be illuminated and are permitted in Table A.1 (found in Appendix A) for the applicable lighting zone in Table 8 (Table 9.4.2-1 in ASHRAE 90.1-2022).

Table 9.4.2-1 Exterior Lighting Zones

Lighting Zone	Description
0	Undeveloped areas within national parks, state parks, forest land, rural areas, and other undeveloped areas as defined by the *authority having jurisdiction*
1	Developed areas of national parks, state parks, forest land, and rural areas
2	Areas predominantly consisting of *residential* zoning, neighborhood business districts, light industrial with limited nighttime use and *residential* mixed use areas
3	All other areas
4	High-activity commercial districts in major metropolitan areas as designated by the local jurisdiction

Table 8 - Exterior lighting zones (2) (ASHRAE, 2022).
©ASHRAE, www.ashrae.org. (2022) ASHRAE Standard-90.1.

Table A.1 lists different exterior applications and the allowances for each lighting zone as well as the controls required for that application. There is also a base site allowance section that has allowances for each lighting zone. Trade-offs mean compensating for one missing prescriptive requirement by exceeding a different requirement and are only allowed between the applications listed in the “tradable surfaces” section of the table (ASHRAE, 2022).

Basic Needs for Outdoor Lighting

The need for outdoor lighting arises from a delicate balance between the convenience and feeling of safety that artificial illumination provides and the preservation of nature. Artificial lighting at night is utilized for a multitude of reasons, including enhancing the feeling of security, extending the accessibility of activities, illuminating pathways for wayfinding, and adding to or emphasizing architectural features and design. Finding common ground between well designed nighttime illumination and minimizing harmful impacts is a challenging task. Excessive and unshielded artificial lighting can contribute to light pollution, disrupt natural ecosystems, impact human health, and hinder our ability to appreciate the night sky. Balancing the functionality of outdoor lighting with the preservation of natural darkness presents a significant challenge. This section will discuss how lighting can affect safety, or the perception of it, as well as aesthetics.

Safety

Artificial lighting at night serves many safety-related purposes involving pedestrian safety, traffic safety, and general accessibility. Research from the Israel Science Foundation categorizes outdoor lighting as “an important component of the urban environment” stating that it is a “major contribution to the pedestrians’ overall feeling of safety and comfort after natural dark” (Portnov et al., 2020). One aspect of artificial lighting at night is the promotion of the surveillance of people in outdoor spaces. Well-lit areas are a deterrent for criminals by illuminating hiding spots that darkness often lends. Removing this sense of being concealed often correlates to a reduction in crime.

Another aspect of outdoor lighting is the “highly visible sign of investment”, which can lead to crime reduction from a more social perspective (Welsh et al., 2022). Improving street lighting indicates to those who live nearby that efforts are being made to improve and invest in their neighborhood (Welsh et al., 2022). This then leads to a more positive view of the neighborhood and increased community pride, optimism, and cohesion (Welsh et al., 2022). Communities are impacted by lighting and often take part in watching for criminal activity. Increased lighting thus leads to more positive views from those living nearby.

Many different studies on crime reduction and lighting have been conducted within the past decade or two, with somewhat differing results at times. The Criminology and Public Policy released an evaluation of some of said studies, concluding that "street lighting continues to be a highly effective intervention for preventing crime in public places" (Welsh et al., 2022). This evaluation sets artificial lighting at night as a positive contribution in the reduction of crimes. This review of studies concluded outdoor lighting of streets resulted in a crime reduction of almost 15% compared to similar control areas (Welsh et al., 2022). While this evaluation draws a positive correlation between lighting and safety, many studies on this topic report conflicting findings. Some of these studies fail to consider the impact of color temperature, glare, or controls. The majority of the thorough and credible studies, however, assert that lighting had no significant correlation to crime levels.

The relationship between lighting and crime is complex and hard to describe. There are several aspects of safety in regard to outdoor lighting including traffic, pedestrian, and property. The following subsections analyze the role that lighting plays in each of these areas in an attempt to gain a more complete conclusion.

Traffic

Traffic safety is a big part of outdoor safety impacted by artificial lighting at night. "The World Health Organization shows that approximately 1.35 million people die every year in traffic related accidents" (Tavares et al., 2021). Almost half of car crashes occur during the evening and early morning hours (Rice, 2009). Additionally, the likelihood of being killed in a crash during these hours is as much as three times greater than during the daytime (Rice, 2009).

Traffic accidents are widely understood to be a significant health threat in urban areas. In 2015, the United Nations created a long-term, comprehensive strategy to tackle the largest global obstacles related to sustainable development. The result is a list of 17 goals to achieve a better and more sustainable future by 2030, called the Sustainable Development Goals (SDG). One of the main targets of one of these goals, was to achieve a 50% reduction in deaths by traffic accidents. According to the 2020 SDGs report, however, within five years these death rates decreased slightly at first but then began to rise again (Guterres, 2020). Thus, this target was one of six assigned as critical in the report.

The 093-1992 report from the International Commission on Illumination (CIE) concluded from over 50 studies that lighting presented a positive influence in reducing the number of traffic accidents in 85% of the cases (International, 1992). More recent studies indicate similar conclusions. A study from New Zealand supports that lighting influences traffic safety. This study indicates a strong correlation between the average illumination level of the road and vehicle crashes, with a stronger relationship for more serious crashes (Jackett et al., 2013). As shown in Figure 6, results indicate that safety improves with greater illuminance until approximately 16 lux (1.5 fc) where safety then decreases with increased illumination (Frith et al., 2015). “The largest night-to-day crash ratio reductions attributable to road lighting on higher-speed roads were on motorways (31%), followed by divided highways (24%), followed by single carriageway roads (17%)” (Frith et al., 2015). Lighting can prevent deaths and injuries from accidents and thus plays an important role in traffic safety. As shown by these statistics, characteristics of lighting, such as quantity and quality, directly affect the number and severity of accidents (Tavares et al., 2021). Other characteristics of lighting such as glare are discussed later in this report.

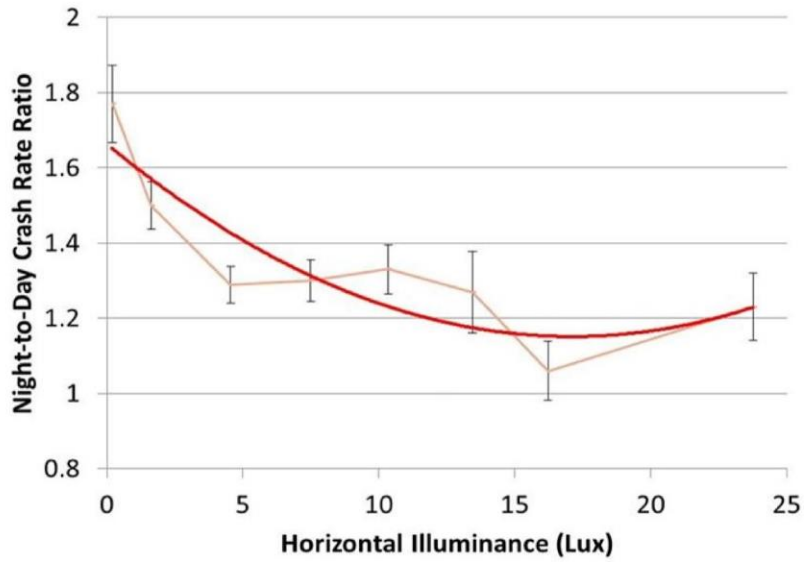

Figure 6 - Illuminance and crashes (Frith, 2015).
Used with permission of NZ Transport Agency Waka Kotahi.

Conversely, the increased use of outdoor lighting is not seen as a positive for traffic safety without opposition. There are studies addressing concerns about potential negative influences of traffic lighting. One such study from Canada analyzed the performance of drivers and the influence of increased illumination. This study found that while increased lighting may be slightly beneficial to older adults, it could also lead to unsafe driving, high speeds, and decreased attention (Easa et al., 2010). Feasible smart lighting solutions can offer potential safety improvements such as “collision avoidance and traffic flow efficiency” regarding artificial lighting at night (Tavares et al., 2021). This article stated visible light communication as one such smart lighting solution, however other technologies, like those discussed later in this report, can also offer safety improvements. The effects of lighting aspects on road accidents are still rarely researched (Tavares et al., 2021).

Pedestrian

Outdoor safety is also impacted by artificial lighting regarding pedestrian safety. "The major part of collisions involving vehicles and pedestrians are in the darkness" (Tavares et al., 2021). A Florida study shows a 42% reduction in accidents from vehicles striking pedestrians at midblock and a 54% reduction at intersections, with the proper lighting of streets compared to dark conditions (Siddiqui et al., 2006).

Additionally, pedestrian safety involves accessibility through outdoor spaces, such as stairs, pathways, and curbs. "It is essential that lighting provides proper visibility and contrast for obstacle distinctions, as well as recognition of different levels and irregularities on paths" (Tavares et al., 2021). Poor lighting is often associated with a high frequency of accidents like slips and falls (Tavares et al., 2021). However, this need for adequate lighting doesn't justify the overuse of exterior lighting. Adding more light to the equation doesn't solve the problem. In actuality, this issue exemplifies the need to implement better designed and more sustainable lighting. Poor lighting is often closely associated with glare, which is detailed later in this section.

These pedestrian accidents are more critical regarding more vulnerable pedestrians like children, the disabled, and the elderly, as they can cause serious injuries. One particular study found that both time and detection distance for older participants can be affected by light levels (Cheng et al., 2016). Generally, the study showed that the vulnerability of older pedestrians can be reduced with better lighting.

Property

As previously discussed, exterior lighting often contributes to higher feelings of safety, however that doesn't necessarily mean it is safer. "Glaring, outward-facing "security" lamps offer little real security if they dazzle potential witnesses to any wrongdoing, and provide a wall of light behind which a burglar can work unseen" (Mizon, 2012). It is difficult to distinguish where the line of deterrence lies. "Indeed, insurance companies do not normally offer a reduction in premiums if "security" floodlights are fitted, due to the lack of evidence that lighting reduces crime" (Mizon, 2012). Studies on the link between crime reduction and lighting are often unreliable. Levels of crime can drastically vary over time, even in a single area, possibly due to variation in individual offenders' activities (Mizon, 2012). Sometimes extra lighting can be of use to criminals. "The presence of lighting can help criminals survey an area and sort out their tools, highlight potential targets, determine easy pickings, and note security lapses and escape routes" (Mizon, 2012). Moving in a bright-lit space is less suspicious than moving in a dark space with a flashlight.

The relationship between lighting and safety is complex and hard to comprehensively understand. It is clear, however, that while outdoor lighting is a necessity in order to ensure the safety of humans, vehicles, and property, excessive illumination doesn't further increase safety and is causing harm to the environment and human health. "A badly lit environment does not, of itself, cause crime" (Painter, 1994). And an overly lit environment does not solve crime. Safety is a factor to be considered when designing an outdoor lighting system, however it is not the only consideration to be made, and should not even necessarily be of the highest priority.

Glare

Another principle that is closely adjacent to safety is glare. "Glare is caused when bright light enters the eye, either directly from a light source (direct glare) or indirectly due to reflection off a surface (reflected glare)" (IES, 2020a). In this context, bright light refers to a source that is much brighter than the surrounding environment (IES, 2020a). This bright light can cause discomfort or even visual impairment also called disability. This impairment of vision can be dangerous, especially in traffic and pedestrian situations. “Discomfort glare can be uncomfortable, distracting, or even painful, and can cause an aversion response even if it does not reduce visibility or affect adaptation” (IES, 2020a). This type of glare, though it does not reduce visibility, does tend to make users react differently than they normally would. On the other hand, the reduction in contrast associated with disability glare is an issue of task visibility rather than visual comfort (IES, 2020a). This type of glare is even more common and harmful to the elderly. Age-related changes to vision include pupillary miosis, retinal detachment, glaucoma, age-related macular degeneration, and cataracts (IES, 2020e). Clouding of the lens, increased floaters, optic nerve damage, increased sensitivity, and degenerated vision are common amongst older individuals (IES, 2020e).

IES standards have recommendations for lumen outputs regarding the glare portion of the Backlight, Uplight, Glare (BUG) rating system defined in ANSI/IES TM-15-20: Luminaire Classification System (LCS) for Outdoor Luminaires pertaining to the mitigation of glare. Figure 7 below represents a visual representation of BUG ratings.

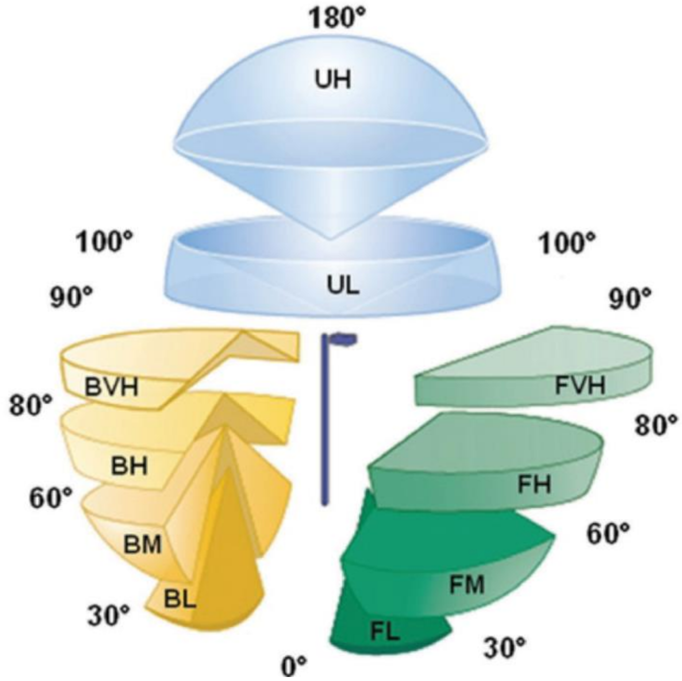

Figure 7 - BUG ratings (IES, 2020a).

Reprinted from ANSI/IES LP-2-20, *Lighting Practice: Designing Quality Lighting for People in Outdoor Environments*. New York: Illuminating Engineering Society, 2020.

The blue portion of Figure 7 represents the different levels of uplighting and how that is represented in the rating. The green section represents front lighting in many different levels corresponding to typical angles. Similarly, the yellow section represents backlighting and its many levels and angles.

The angles that pertain to glare include four zones: FVH, FH, BVH, and BH. The lumens emitted from a luminaire from within these zones are compared to predetermined levels in TM-15-20 to define the glare rating of the fixture. For fixtures mounted about eye level, it is often the light from the sixty to ninety degree range that enters the field of view against the darkness of night (IES, 2020a). “The BUG ratings help determine the appropriateness of a luminaire for pedestrian use, thereby aiding lighting designers in making equipment decisions for people in outdoor environments” (IES, 2020a).

Aesthetics

In addition to safety and comfort requirements, outdoor lighting is often utilized to achieve certain architectural and aesthetic goals. Facade lighting and landscape lighting are great examples of this. The only purpose for these types of lighting is to achieve an aesthetic function. Architectural lighting creates a welcoming and visually appealing ambiance which attracts occupants, enhances the overall experience of outdoor spaces, and creates a lasting impression. Additionally, architectural lighting can highlight architectural features, branding elements, or signage, effectively promoting businesses and increasing visibility, especially during evening hours.

While aesthetics tends to be low priority, it plays a crucial role in shaping the perception of a project. It may not seem as important or necessary as the role of safety or even comfort, but the way that lighting contributes to the architectural design should not be discounted. That isn't to say that it should be done carelessly or without thought to the impact on the environment, but good sustainable design doesn't have to be bland and basic.

Control Considerations

The International Dark-Sky Association (IDA) asserts that roughly one-third of all exterior lighting in the United States is wasted (Jamal et al., 2022). There is a massive amount of excess lighting, especially in commercial applications. Wasted or excess lighting is lighting that is not needed, left on when not in use, too intense (over-illumination) or poorly directed (like uplight). Utilizing shielded, low-glare, low-wattage lighting minimizes this excess lighting (Jamal et al., 2022). These three measures are a simple way to quickly minimize light pollution, however, there are also extensive emerging tools and methods that can be implemented for even greater impact.

Technology is rapidly growing both inside and outside of the lighting industry. "With the specification of modern lighting controls, a much finer balance can be struck through rapid experimentation to be more intentional with light and to find the most harmony with the natural world" (Slade, 2022). Additionally, these changes are happening in all different areas of the industry, and they have a significant potential for positive change. These positive impacts can be found from individual changes, but the most opportunity will likely be from combinations of new technology. The integration of sensors, real-time data analytics, and communication is creating adaptive solutions for lighting to increase energy savings and help create safer exterior environments (Zulfizar, 2023).

This section will discuss both new and existing technologies and how they can be utilized in sustainable exterior lighting design. Much of the following technology has existed for quite some time now. What this section is focusing on is how this technology can be used in new ways and how it can be better implemented. Some of these methods haven't been utilized in exterior lighting applications. This report asserts that even greater results can be found by the combined use of multiple controls and technologies. The largely existing technology that will be discussed are automatic controls, light sensors, and integration with building automation systems (BAS). Additionally, a few newer technologies are also discussed. These will include motion sensors, object triggering, and artificial intelligence.

Existing Technology

Existing technology regarding control and automation of exterior lighting has been in place for many years. Furthermore, these methods of control are quite successful in seeing energy savings. However, this report asserts that further use of and integration with other control methods will result in even higher savings and in more overall sustainable design practices. Automatic controls, photocells, and integration with building automation systems all hold large potentials for better implementation.

<u>Automatic Controls</u>

One of the most impactful methods of conserving energy use within lighting design is automatic controls. It is very difficult to achieve energy savings with an uncontrolled lighting system (Atis et al., 2016). Outdoor lighting controls also obviously have drastic impacts on the night sky by greatly reducing the amount of time lights are on unnecessarily. Automatic controls are a large part of the advancements being made within the lighting industry. “The smart lighting market is expected to grow from $13.4 billion by 2020 to $30.6 billion by 2025, with a relevant part related to control applications regarding improvements on energy savings” (Tavares et al., 2021). The developments in intelligent controls have driven exterior lighting systems into groundbreaking adaptability and functionality (Zulfizar, 2023).

Smart lighting allows for remote monitoring, controlling, and automation of lighting by way of a controller. Oftentimes, this can be done from anywhere by using a phone with internet access. “This level of control and flexibility can enhance the ambiance of homes and workplaces alike, and additionally provides further opportunities to save energy" (Ibrahim et al., 2023). The ability for users and building owners to have remote access to their lighting systems is game changing. Being able to see, monitor, and control the system from afar makes it so much easier to adjust the system as needed to maximize energy efficiency and minimize night sky problems.

Exterior lighting system retrofits can achieve high energy savings. A retrofit project in Italy including timing and dimming of public exterior LED lighting systems resulted in 84% energy savings (Tavares et al., 2021). The performance and efficiency of smart lighting controls has been widely confirmed throughout the industry (Acosta et al., 2023). Despite the high potential for energy savings, outdoor lighting controls are not implemented as often as in indoor applications. Comparing indoor and outdoor controls applications shows a "lack of implementation in control solutions" in exterior projects (Tavares et al., 2021). Although automatic controls have not yet been as widely implemented in outdoor applications, there is a massive amount of savings potential with this technology and an increasing number of projects are taking advantage of this potential. Furthermore, they are increasingly being utilized as they become more prevalent in code requirements.

Outdoor lighting controls aren't as prevalent as indoor lighting controls for several reasons. These controls tend to be more complex and expensive because they require durability, weather-resistance, and experience varying conditions due to the sun and weather. Maintenance also poses a larger obstacle because these systems are exposed to harsher conditions than indoor systems. Additionally, technological integration is more difficult with existing outdoor lighting systems since they are typically older and less sophisticated, however increasing prevalence of these technologies will likely cause outdoor lighting to become more sophisticated and common.

Daylight/Photocell Sensors

Daylight sensors are key to the advancement of exterior lighting because they detect illumination levels to determine when artificial light is needed. Without daylight sensors, the lighting system would likely have an accidental overlap with natural lighting, especially during seasonal changes like daylight savings time. This impacts night sky issues by only illuminating the sky when it is photometrically necessary. Historically, these photocells are used to limit the amount of artificial lighting during the early evening and late morning hours when it is not necessary. This does result in a reduction of energy consumption, but further use of these daylight sensors holds even more savings potential.

Photocells are not a new technology but recently they are being integrated with other technologies to create new, advanced systems. “Sensors deployed within the street lighting infrastructure play a crucial role in collecting real-time data” (Zulfizar, 2023). These sensors enable the system to be responsive to the light conditions caused by the sun. “Additionally, environmental sensors can monitor factors such as temperature and weather conditions, further enhancing the system’s adaptability” (Zulfizar, 2023). Sometimes there are issues with photocells that cause them to not function accurately. These added environmental sensors and capabilities add another layer of ensuring that the fixtures are on when they are needed and off when they aren’t. Additionally, photocells are not always sensitive enough to come on when it is cloudy or stormy, or conversely are too sensitive and come on before it is necessary. These sensors could also further be implemented with dimming capabilities that would allow for energy savings of having fixtures on at half capacity when some additional lighting is needed but full illumination is excessive. This additional prediction of upcoming weather and conditions allows for a more efficient and effective control system.

Integration with Building Automation Systems

Building Automation Systems (BAS) are very common throughout commercial building applications. Indoor lighting, HVAC, security, and audiovisual systems are being controlled and monitored through a low-voltage communication system. These BAS, though increasingly typical in indoor applications, are not being implemented in many outdoor applications. These systems are not always practical in outdoor environments largely due to interference and noise being considerably higher outdoors (Ndjiongue, 2018). This disruption or modification of a signal as it is traveling creates unwanted signals. Though tying exterior lighting to the BAS still uncommon, they are occurring more frequently than before. This is dependent on an existing BAS, so this wouldn't be of much help for projects without a building (such as parks).

Utilizing the BAS for indoor and outdoor systems could dramatically impact the efficiency, functionality, and adaptability of the system for a seamless flow of experience for occupants by allowing for scheduling, dimming, motion and object detection, and greater control of lighting all from one integrated system. All of these functions reduce excess lighting which aids in restoring the night.

Emerging Technology

Newer technologies are emerging as well. These types of control methods offer unique solutions to problems the exterior lighting industry has faced for decades. The technologies that this report will discuss are motion sensors, object triggering, and artificial intelligence.

Motion Sensors

Motion sensors detect movement that indicates the presence of people, vehicles, and animals which allows for adaptation of illumination of the system. "Street lighting has undergone a paradigm shift, evolving from simple illumination devices to intelligent systems capable of adapting to the dynamic needs of modern cities" (Zulfizar, 2023). These intelligent systems incorporate motion sensors, real time data analysis, and advanced communication technology. Motion sensors are not entirely new either, but they are continuing to be used in more advanced ways, and there is a lot of potential for application to outdoor systems.

Newer motion technology allows for object triggering, where motion can be identified as a person, car, animal, bicycle, etc. One example of this type of technology being utilized is Amazon Go, a new type of convenience store where sensors track the movement of customers through the store and then charge their account instead of paying at a cashier (Wankhede et al., 2018). This shows that while it isn't currently being used in exterior lighting, it is being successfully utilized in other ways. In relation to lighting, this technology allows for advanced control options dependent on the type of motion detected. Additionally, the identification of motion at one sensor can be integrated with sensors further away to predict movement in that direction and illuminate the path.

A 2014 study conducted in India was one of the first studies to delve into modern sensing and controls of outdoor lighting for streetlights. This study used automatic control switching of streetlights to create "dynamic control statistics" using sensors and wireless communication on light poles (Suganya et al., 2014). It used a system of sensors on the poles to detect movement of vehicles. Additionally, it automatically controlled the illumination of the streetlights based on this detection to effectively save energy. This system was automatically controlled to be full-on, full-off, as opposed to dimming in between, which made it particularly appropriate for low traffic areas. In higher traffic areas, full-off is likely not the safest option, but a few minor adjustments to this system could be made to balance safety and savings. The authors of the study stated that nearly half of the energy budget of cities is consumed by street lighting (Suganya et al., 2014). Thus, it is clear that drastic energy savings potential lies in the outdoor lighting sector.

A similar 2023 study from furthers the analysis of roadway lighting controlsto increase energy saving potential by utilizing more modern technology. This application used sunlight sensors to detect natural illuminance and turn off the artificial street lighting, as well as detect nightly darkness and turn on the streetlights. This system additionally utilized infrared sensors to detect vehicles and people moving on or near the road (Dhoke et al., 2023). Low-intensity illumination was used when no vehicles or people were detected, and high-intensity illumination was used when there was detected movement. These types of systems allow for "energy savings during low-traffic periods and increased illumination when needed," which maximizes both security and functionality (Zulfizar, 2023). This would have a large impact on night sky issues by drastically reducing the amount of time that lights would need to be on at full capacity reducing the amount of illumination contributing to issues like sky glow, uplight, and light trespass.

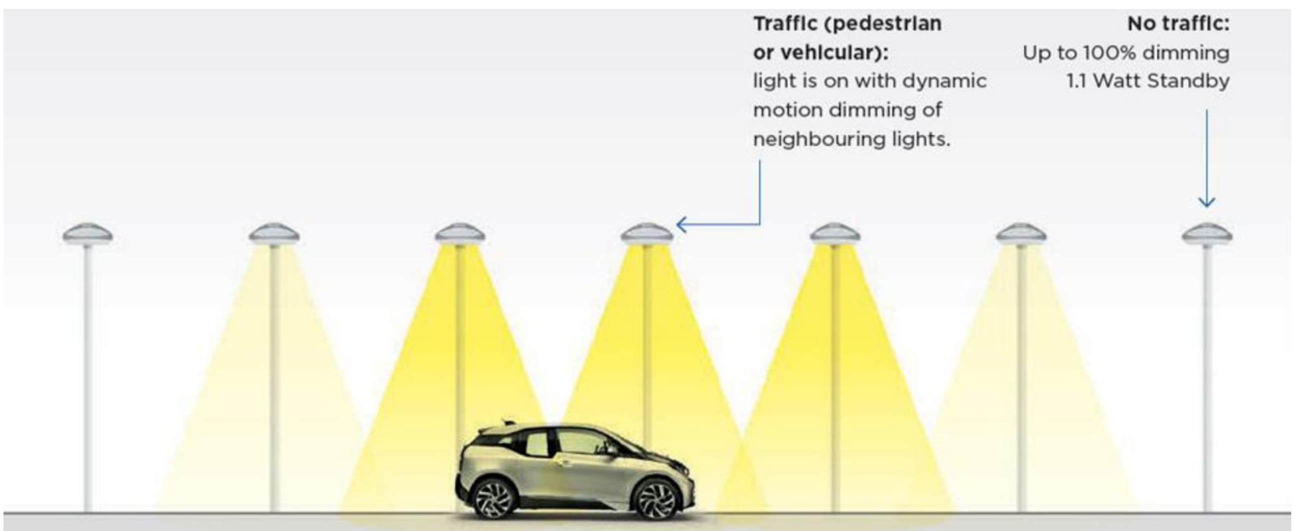

Figure 8 - Dimming street lighting control system (Zulfizar, 2023).

<u>Artificial Intelligence (AI)</u>

AI is increasingly becoming prevalent in many aspects of the engineering industry. These emerging AI tools are effectively working to attain sustainability goals such as energy reduction

(Balsalobre-Lorente et al., 2023). While AI is becoming increasingly utilized, it is also being further developed into even more cutting-edge tools.

A study from Turkey chose a specific AI tool, to control and monitor an exterior lighting system. This system was the first developed in which this technique was used in this manner (Atis et al., 2016). The system ensured that lamp groups were turned on and off when most effective. These groups were activated or deactivated depending on seven different conditions in order to most appropriately control them. These seven inputs include manual, objects, specific time periods (summer, holidays, weekends), level of security, motion, real-time, and photocell. The system is activated by adjusting between 50% and 100% until after 11 pm, when it adjusts between 30% and 100%. The developed system was designed to be able to be integrated into sustainable and intelligent building systems because it uses daylight more efficiently and conserves more electrical energy (Atis et al., 2016). This study found significant savings compared to the previous year, and comparable systems would likely achieve similar results.

Even though there are not many exterior lighting applications utilizing AI tools, similar applications are being made in other industries (Berardini, 2021). These applications include person detection in security, object detection in retail (contactless checkout), and even driverless cars. People and vehicle detection tools have a very high potential for energy savings in outdoor lighting and could solve a lot of the issues being seen with outdated motion sensors. As discussed previously, motion detectors can identify when people or cars are moving underneath or near light fixtures and trigger them to turn on. The benefit of AI, however, is that it can distinguish the movement of vehicles from the movement of people or animals and adjust the lighting accordingly instead of simply turning the lights on regardless of what type of motion. This would enable systems to not waste excessive illumination when, for example, an animal triggers the motion sensors, which would reduce energy consumption. Similar to the above subsection, this would have a positive impact on night sky issues.

Data Gathering and Analysis

Current practices continue to contribute to light pollution with drastic environmental and health effects, however, even small changes during design can greatly reduce or even eliminate this. The National Society of Professional Engineers has published a code of ethics for engineers that includes "fundamental canons", that state the highest level requirements of an engineer. The first of those being that engineers shall "hold paramount the safety, health, and welfare of the public" (NSPE, 2019). Additionally, this code of ethics also includes a list of professional obligations that engineers have. Most notably that: "Engineers shall at all times strive to serve the public interest" (NSPE, 2019). Thus, it is the obligation of engineers and designers to have an active role in creating and advancing the standards and practices associated with sustainability that are utilized during design. As discussed above, there are many advancements being made regarding both the knowledge about light pollution as well as the technology being produced that can be implemented to reduce the effects of artificial lighting.

In this Data Gathering and Analysis section, an analysis and review of a particular existing exterior lighting application in Manhattan, Kansas will be detailed. The exterior lighting application that was chosen is West Loop shopping center. This approximately 214,898 square foot (5 acres) shopping area. As shown in Figure 9 below, this area is defined by Claflin Road on the north, Westport Drive on the east, Anderson Avenue on the south, and North Seth Child Road on the west.

The west side of this shopping center is largely occupied by Dillons supermarket. The east side is occupied by Marshalls, Joann Fabric and Crafts, and a strip center including SunTan City, Little Apple Brewing Company, Bellus Academy, Moon Massage, Little Caesars, Smoothie King, Manhattan Appliance and Sleep Source, The UPS Store, True Beauty Mhk, Eat the Frog Fitness, Kre8tion Nails, Hair Unlimited, Nespor's Wine & Spirits, RE/MAX Signature Properties, and Salon One & Spa. It also houses Tommy's Express Car Wash, Scooter's Coffee, McDonald's, KS StateBank, and a dentist office.

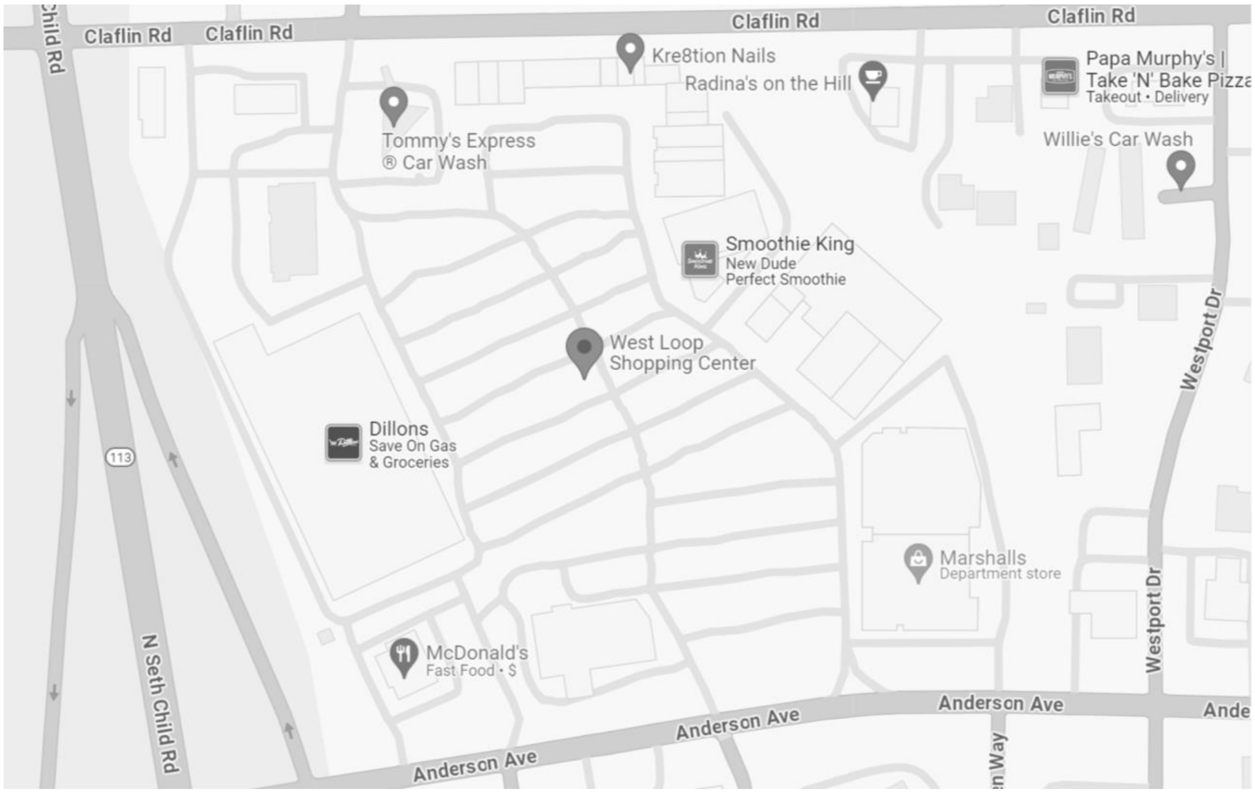

Figure 9 – West Loop map (Google, n.d.)

An evening evaluation of the existing lighting system was conducted. The illumination levels represent the quantitative analysis of the space while the following images represent the qualitative visual analysis. The measured illumination levels are identified and compared to IES recommendations. The photos show the existing state of the lighting for parking lot, signage, façade, and pedestrian areas. A detailed qualitative analysis is then introduced.

Quantitative Analysis

Figure 10 is the lighting plan that represents the existing exterior lighting system of the West Loop shopping center's parking lots. There are other luminaires that make up the lighting system of the center (such as soffit, internally illuminated signs, and wall mounted), but they are not included in the figure below because it would clutter the image making it harder to use effectively. The blue circle represents the bus stop. The larger grey squares represent the taller pole mounted luminaires, and the smaller grey squares represent the shorter pole mounted luminaires. The locations of illumination measurements are also shown as a red area. This area was chosen for measurements because the entire parking lot is illuminated similarly and this area was clear of obstructions like cars, while the rest of the lot was fairly full.

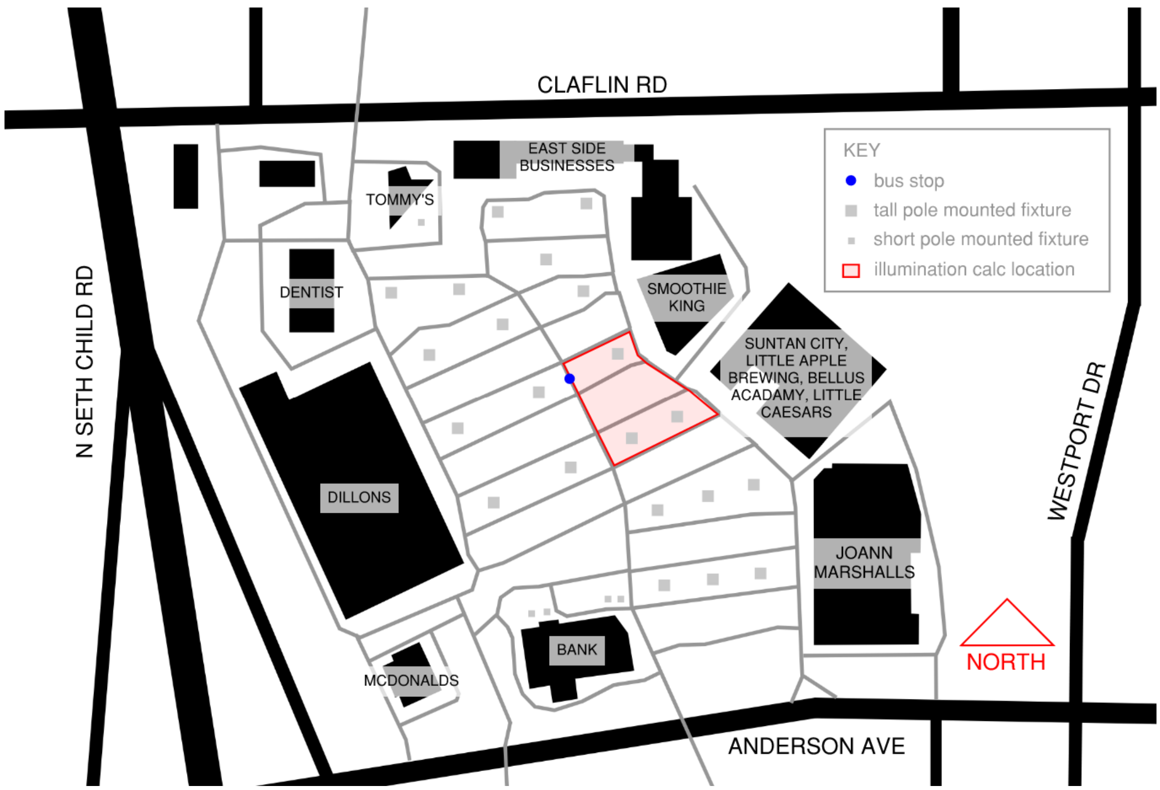

Figure 10 – West Loop lighting plan

Figures 11 and 12 are sketches of what the lighting system looks like currently at the main portion of this shopping center, Dillons. These figures go hand in hand with the images that will follow in the Visual Analysis section.

Figure 11 - Dillons lighting sketch

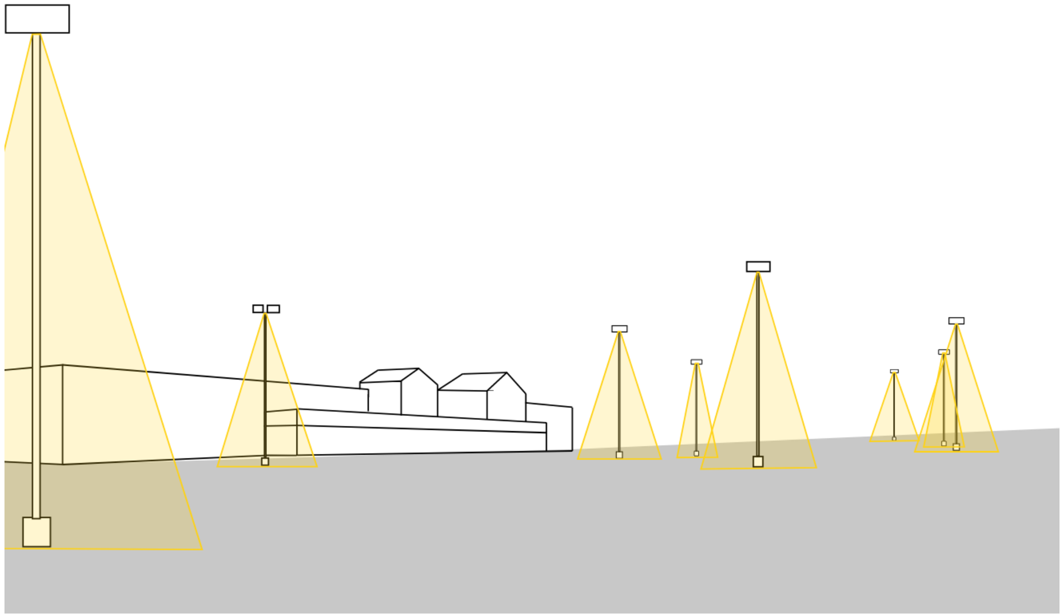

Figure 12 - Dillons modeled sketch

Several illumination measurements were taken at various areas of West Loop shopping center. All of these illuminations were horizontal measurements. Multiple measurements were taken at each area and the average of those measurements are listed. When the values varied greatly a new category was listed (for example the different areas at Tommy's). The door entrance measurements were taken at the main doors of the businesses. The parking lot pole mounted luminaire measurements were taken at the side and front of the pole. These fixtures have two luminaires on each pole; the side illumination is on the side in between both luminaires while the front illumination is on the side that is directly under one luminaire, as shown in Figure 13. These illumination measurements are listed in Table 9, below.

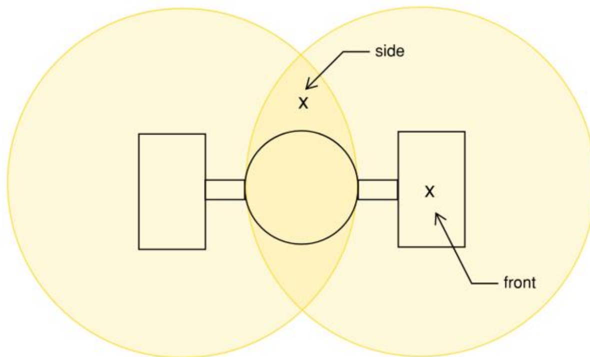

Figure 13 – Luminaire illumination measurement location

For the parking lot, measurements were taken near the base of poles and at equal distances between poles to gain information about maximum and minimum illuminances. This was used to evaluate compliance with guidelines. The “between three poles” measurement was taken in between the three poles in front of Smoothie King. This measurement is comparable to a measurement between four poles. If the illumination between three poles is high enough to meet the recommendations, then the Illumination between four will be enough to meet them.

The entrance measurements were taken directly at the ground of the doors to the building. The bench measurement is taken at seat level underneath the slatted covering (shown in Figure 21); this area is not directly illuminated, but rather indirectly illuminated from the surrounding pole mounted fixtures. Two measurements were taken at the bus stop sign, one at the sign and the other at the ground directly below the sign. The drive-thru measurement was taken at the ground under the soffit lights.

Table 9 – Measured illumination levels

Illumination Levels			
Measurement Location	**Illumination (horizontal)**	**IES Recommendation**	**Recommendation Source**
PARKING			
Parking Lot Pole Mounted Fixture	Side – 4 fc	0.2-3 fc	RP-8-22
	Front – 2.8 fc	0.2-3 fc	RP-8-22
Halfway Between Two Poles	3 fc	0.2-3 fc	RP-8-22
Between Three Poles	2.5 fc	0.2-3 fc	RP-8-22
ENTRANCES			
Dillons Entrance	8.5 fc	2-4 fc	RP-43-22
Appliance and Sleep Entrance	7.9 fc	2-4 fc	RP-43-22
Eat the Frog Fitness Entrance	11.5 fc	2-4 fc	RP-43-22
Kre8tion Nails Entrance	4.7 fc	2-4 fc	RP-43-22
Nespor's Entrance	6.3 fc	2-4 fc	RP-43-22
JoAnn Entrance	7.8 fc	2-4 fc	RP-43-22
SIDEWALKS			
Bench	1.5 fc	0.5-1.5 fc	RP-43-22
Bus Stop Sign	Sign – 16 fc	0.5-1.5 fc	RP-43-22
	Ground – 4 fc	0.5-1.5 fc	RP-43-22
PHARMACY DRIVE-THRU			
Under the canopy	13.5 fc	0.2-3 fc	RP-8-22
Next to canopy	7.1 fc	0.2-3 fc	RP-8-22
Road leading to canopy	2.9 fc	0.2-3 fc	RP-8-22
TOMMY'S			
Drive-thru	27.6 fc	0.2-3 fc	RP-8-22
Road leading to drive-thru	7.5 fc	0.2-3 fc	RP-8-22
BANK			
Bank sidewalk	4.4 fc	0.5-1.5 fc	RP-43-22
Bank entrance	10.8 fc	2-4 fc	RP-43-22
Bank drive-thru	9.3 fc	0.2-3 fc	RP-8-22
Road leading to drive-thru	5.9 fc	0.2-3 fc	RP-8-22

The IES has illuminance recommendations for each of these areas (building entrance, sidewalk, and parking lot). General exterior lighting applications such as building entrance and sidewalk recommendations are found in RP-43-22. The parking lot illumination recommendation comes from RP-8-22: Lighting Roadway and Parking Facilities. This Recommended Practice lists minimum design recommendations for parking lot and street lighting areas. The general consensus for maximum recommendations is 2-3 footcandles. The parking lot minimum recommendation is 0.2 footcandles (IES, 2022b).

The building entrance illumination levels are quite a bit higher than the recommendation, however seeing as the interior space is so highly illuminated, it makes some sense to have higher illumination at the transition so as to have more comfortable transitions between inside and out. The walking surface illuminations meet the recommendations. Furthermore, the parking lot illuminations meet the parking lot minimum recommendations. Since the illumination levels are at the high end of or slightly above the recommendation range, we can conclude that this shopping center is slightly over illuminated. This is one of the key aspects that should be targeted for alleviation of night sky issues. This will be discussed further in the Design Recommendation section.

The max to min illumination ratio of the parking lot is around 4:2.5. A max to min illumination ratio is simply the highest illumination level compared to the lowest illumination level. In this case, the high is directly under one pole while the low is in between three poles. Taking this into account, it can be seen that this space is uniformly lit with little distracting or uncomfortable contrast. Comparing this to the published minimum recommendation of 20:1 max/min ratio, this space conforms with IES recommendations. An evenly spaced reduction in illumination will better meet the IES recommendations without sacrificing the uniformity, rendering, or contrast that was accomplished successfully in this project.

Visual Analysis

In addition to existing illumination levels taken via light meter at West Loop shopping center, a series of photographs were also taken to document the current state of the lighting system. The following discussion provides details of the images by area, including the Dillons parking lot (Figures 14-23), the east side parking lot (Figures 24-29), the Bank parking lot (Figures 30-33), and the area surrounding Tommy’s car wash (Figures 34-35). Then a detailed analysis of the illumination and non-illumination criteria from IES publications will be discussed in reference to night sky issues.

Dillons parking lot

One of the main areas of West Loop shopping center is Dillons, and the parking lot in front of it (to the east). About half of the entire center’s parking lot is dedicated to Dillons supermarket. This area of the parking lot contains 8 of the 21 pole mounted fixtures. Additionally, there are wall mounted fixtures along the sides of the building, internally lit store signs, and can lights near the main entrances, sidewalks, and pharmacy drive-thru. In the middle of the parking lot is a bus stop which consists of a bench and an externally lit sign depicting the routes.

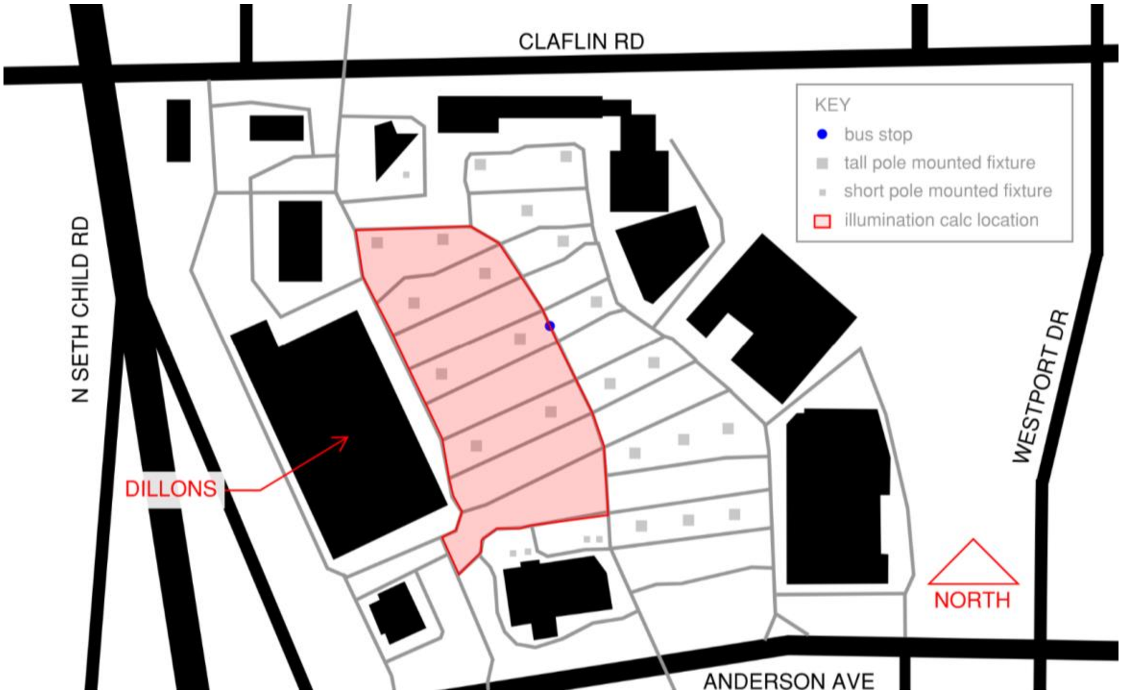

Figure 14 - Dillons area

Figure 14 highlights the parking lot in front of Dillons that correlates with the photos in Figures 15-23.

Figure 15 - Dillons

Figure 15 is of the east face of Dillons, taken from the bus stop area.

Figure 16 - Dillons parking lot

Figure 16 of the east face of Dillons was taken from the bank parking lot.

Figure 17 - Dillons side

Figure 17 is of the northeast corner of Dillons, taken from the parking lot.

Figure 18 - Dillons utility door

Figure 18 is of the north utility door taken from the sidewalk that runs along the east face of the building.

Figure 19 - Dillons main entrance

Figure 19 shows the entrance of Dillons. It was taken from the northeast end of the building.

Figure 20 - Dillons drive-thru pharmacy

Figure 20 shows the pharmacy drive-thru which is located on the south side of the building.

Figure 21 - Bus stop bench

Figure 21 was taken from the bus stop. It shows the covered bench with the east face of Dillons in the background.

Figure 22 - Bus stop sign

Similarly, Figure 22 was taken from the same area but shows the signage for the bus stop.

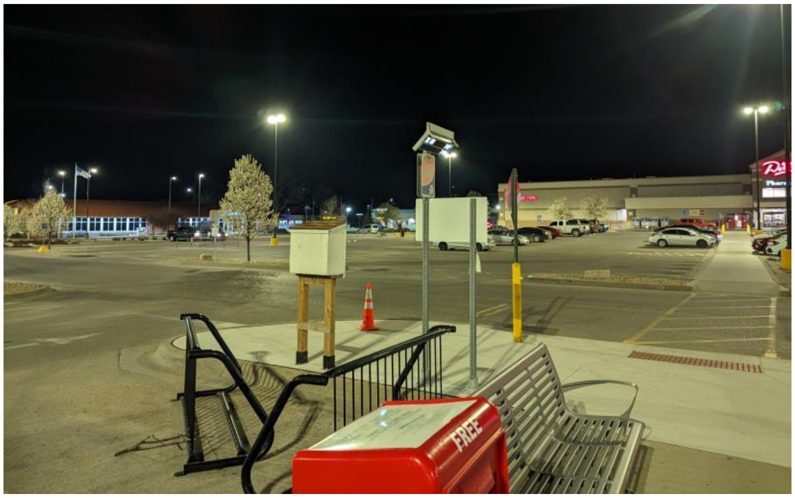

Figure 23 - Bus stop area

Figure 23 was also taken from the bus stop area and shows a larger view of this area.

East side parking lot

The east side parking lot of this shopping center contains the remaining thirteen pole mounted fixtures. Some of these businesses also utilized canopy lighting or wall packs along the side of the building for pedestrian and wayfinding purposes. There are also lit signage on most of the shops along this side.

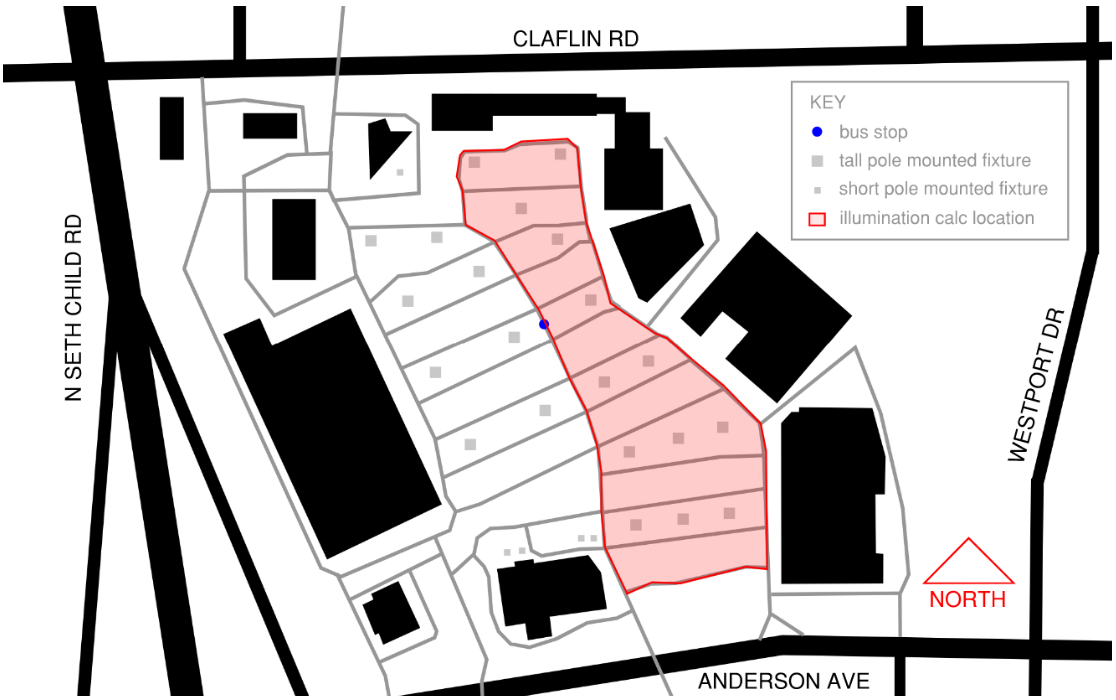

Figure 24 - East side area

Figure 24 highlights the area of this shopping center that correlate to the photos in Figures 25-29.

Figure 25 - Marshalls & Joann

Marshalls and Joann west faces are shown in this picture that was taken from the bus stop.

Figure 26 - East side

More of these businesses’ west faces are shown in this image that was taken from the adjacent parking lot.

Figure 27 - Middle section

Similarly, these businesses' west faces are shown from a slightly more northern angle.

Figure 28 - Smoothie King

Here, the northern buildings are shown from the south end of the adjacent parking lot.

Figure 29 - East side parking lot

An additional view of these northern businesses is shown from the middle of the parking lot.

<u>KS State Bank</u>

The south end of the shopping center is occupied by KS StateBank. The bank has four additional pole mounted fixtures that are shorter than the main parking lot poles. These fixtures are utilized for illuminating the bank parking lot as well as the flagpole near the main entrance. The bank also has additional downlighting at the main entrance and along the perimeter soffit of the building.

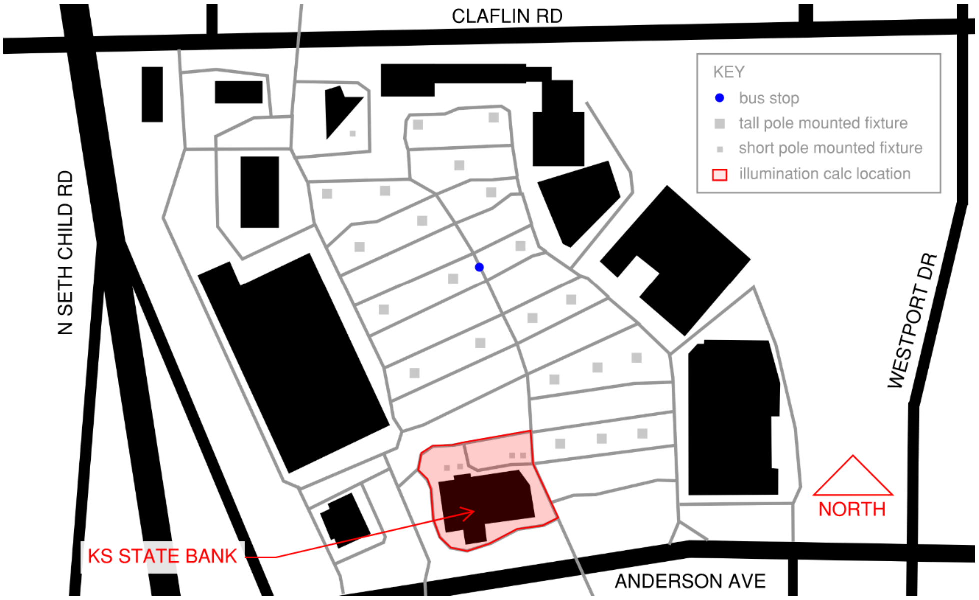

Figure 30 - Bank area

Figure 30 highlights the area of the shopping center correlating to the photos in Figures 31-33.

Figure 31 - Bank side

This image shows the northwest corner of the bank with Marshalls in the background.

Figure 32 - Bank front

Here, the north face of the bank was taken from the bank parking lot.

Figure 33 - Bank parking lot

This view of the north face of the bank and parking lot lighting was taken from the end of the lot.

Tommy's carwash

Opposite the bank, on the north side of the shopping center, is Tommy's Carwash. This area of West Loop has an additional (shorter) pole mounted fixture. The car wash also has wall mounted fixtures above doors, lit signage, canopy lights, and LED strip lighting. Additionally, light from inside spills out from the windows of the car wash. The lighting surrounding the car wash is also quite a bit cooler in CCT value than the rest of the center's lighting.

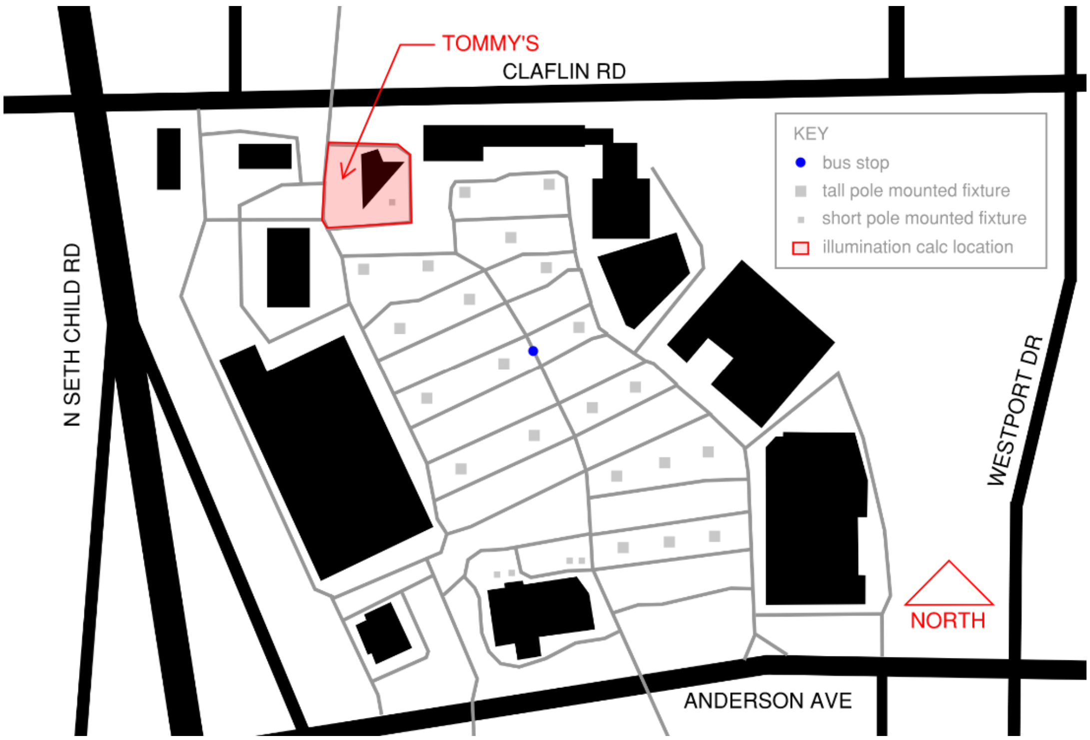

Figure 34 - Tommy's area

Figure 34 highlights the area of the center occupied by Tommy's carwash shown in Figure 35.

Figure 35 - Tommy's

Figure 35 shows the south side of the car wash from the north end of the Dillons parking lot.

Qualitative Analysis

The following section details the qualitative means for analysis of the West Loop shopping center lighting system. The following metrics will be discussed: hierarchy of illumination, five principles of responsible outdoor lighting, luminaires, wattage, glare, uniformity, and safety. This analysis is only looking at the existing system. Recommendations will follow in the Design Recommendations section.

<u>Hierarchy of illumination</u>

Hierarchy of illumination is the strategic use of light to emphasize or highlight certain areas or elements in a design. Varying light levels create a visual hierarchy that guides the viewers' attention. Done well, the hierarchy of illumination complements both the design and purpose of the project, aiding in a balanced design. The hierarchy of illumination for this shopping center was evaluated. The first level consists of the main parking lot lighting, the pole mounted luminaires. The second level is made up of the door illumination for wayfinding, mostly consisting of can luminaires. The third level consists of the shorter light poles. The fourth level is the wall mounted luminaires, primarily utilized around the utility doors. And finally, the fifth level is the decorative lit signage and LED strip lighting. This is a pretty standard style hierarchy that tends to create a balanced design.

Five principles of responsible outdoor lighting

The five principles of responsible outdoor lighting: useful, targeted, low light levels, controlled, and color, were also evaluated. As previously discussed, these principles are key to well-designed outdoor lighting. These principles form a basis of design on which more sustainable practices can be applied. These principles, listed in Table 10, are further discussed in the following paragraphs but are detailed even further in previous sections.

Table 10 - Five principles of responsible outdoor lighting

USEFUL
TARGETED
LOW LIGHT LEVELS
CONTROLLED
COLOR

Useful

All of the lighting for West Loop has a clear purpose: the pole mounted luminaires are illuminating the parking lot, the can lights are illuminating the pedestrian focused areas near the buildings, the wall mounted luminaires provide illumination and wayfinding for doorways, and the LED strip lighting is used for advertising. There are a reasonable number of pole mounted and wall mounted luminaires. On the other hand, the number of can lights seems a bit high, seeing as the illumination levels in the areas by these luminaires is high. Additionally, all of the luminaires at West Loop are not mounted too high or too close to the ground.

Targeted

The lighting for this shopping center is targeted well since the luminaires are primarily illuminating where necessary. The luminaires utilized in this project have minimal uplight and are placed far enough away from the project boundaries so as to avoid light trespass. None of the lighting from this shopping center is visibly spilling into the streets that set the boundaries of this space. Based on similar fixture cut sheets, the pole mounted fixtures are likely a U1 classification. This is a good classification for the area but would ideally be U0 so as to completely eliminate uplight since it is entirely unnecessary to have any uplight for this application. Table 11 below, is the table by which uplight ratings for fixtures are determined. It quantifies what these uplight ratings actually look like by providing maximum lumens for each secondary solid angle as is shown in Figure 7 of this report.

Table 11 - Uplight rating (in lumens)

	SECONDARY SOLID ANGLE	U0	U1	U2	U3	U4	U5
UPLIGHT/ SKYGLOW	UH	0	10	50	500	1000	>1000
	UL	0	10	50	500	1000	>1000

Furthermore, as shown in Figure 34 below, the pole mounted fixtures distributions are type VS. This type of distribution creates an even distribution in each direction surrounding the pole to create a square pool of light at its base. With two luminaires attached to each pole one hundred eighty degrees apart, this distribution simply becomes more of an elongated rectangle than a square. Minimal shielding is utilized on these luminaires to prevent uplight, light trespass, and glare. However, light distribution is focused on the areas where it is needed. Thus, these fixtures don’t vary too far from the recommended targets, however there are definitely characteristics that could be improved to better meet these recommendations.

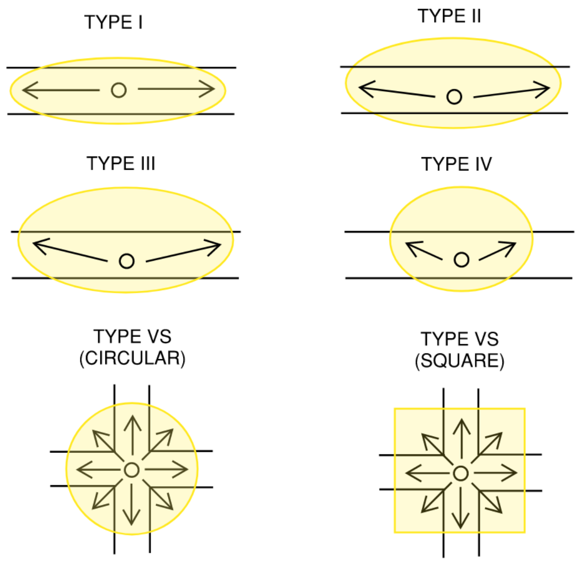

Figure 36 - Distribution classifications

While there is no light trespass extending outside of the project boundaries, there are areas of the project that spill into other areas of the shopping center. The main example of this is Tommy’s carwash. The fixtures surrounding Tommy’s currently have no shielding and are likely closer to a U3 classification. The lighting for Tommy’s currently spills into the main parking lot of the shopping center as well as toward Seth Child Road. This is shown by the almost 7.5 fc measurement, as reference in Table 9, at the road leading toward the drive-thru of Tommy’s. This is lower than the 27.6 fc measured directly at the drive-thru, however, so it can be concluded that this light trespass does not spill past the project boundaries.

Low light levels

The illumination levels of West Loop’s lighting system are relatively appropriate. However, these levels aren’t the lowest recommended. As was mentioned previously in the quantitative analysis, the space has adequate lighting levels but is slightly over illuminated.

The parking lot was adequately lit; cars, roadways, and parking spots were all lit in a manner that made them easily visible. Additionally, there is no visible surface reflectance occurring in the parking lot, indicating while slightly over illuminated these levels aren't so high as to cause major issues. The building entrances were quite a bit higher than recommendations creating a higher emphasis on these areas than necessary. While this does help with wayfinding and with adjusting to the brighter indoor lighting, it is overdone. This could reasonably be done without being twice as illuminated as recommended. The sidewalks by the bus stop were illuminated quite well, they meet the recommendations without going over and the space is illuminated well for the tasks at hand.

The illuminations at Tommy's and the bank are drastically higher than those of any other area in the shopping center. This draws unnecessary attention to these areas and wastes energy. While the tenants want added attention to their space, this can be done without excessive amounts of light. Furthermore, this added attention is typically after hours and thus isn't advantageous enough to warrant the detriment to the night sky.

Controlled

The existing controls of this lighting system are assumed to be a combination of photocell and time clock controls. It is assumed that most, if not all, of the luminaires are controlled all together. Furthermore, it is unlikely that any dimming is being utilized. This lack of advanced controls is missing out on a spectrum of energy savings, functionality, and adaptability. This rudimentary use of controls may have met the code requirements at the time of install, but the design does not meet more current versions of codes and standards as detailed in the Review of Design Documents section.

Color

The color characteristics were done surprisingly well in this shopping center. The color correlated temperature of the shopping center parking lot is estimated to be 3000k-4000k. The color temperature isn't too cool, which minimizes the issues involving blue light that were discussed in a previous section of this report. Additionally, the CCT value also wasn't too warm so as to typically have poorer color rendering. The color rendering of the space was more than adequate, all colors seem to be rendered well. Many different colored cars were present during the quantitative and visual analyses of this space. Each color of vehicle was distinct and easily recognizable. Oftentimes too warm of a CCT value skews color rendition and makes red colored objects difficult to distinguish from black colored objects due to the red and orange wavelengths of the light source. This did not occur at West Loop shopping center. Furthermore, the roads and lines of parking spaces were easy to distinguish.

<u>Luminaires and wattage</u>

The poles that were utilized for this project have two luminaires attached to each pole one hundred eighty degrees apart for a more uniform light distribution. The following figure shows an image of one of these poles with one luminaire operating and the other not, so as to get a clearer idea of what these fixtures look like without the glare from the camera. These luminaires are assumed to be LED. It is thus assumed that they are likely relatively low wattage fixtures.

Figure 37 - Pole mounted fixture

The wattages for the LED fixtures were estimated by utilizing cutsheets for similar metal halide fixtures and finding a LED alternative that produces a similar lumen output. An example of this data is shown in Table 12. Thus, the wattage for tall poles is assumed to be 151W and for short poles 53W. Furthermore, the wall packs are estimated to be 21W and the downlights are estimated to be 26.4W. There are 21 tall poles, 5 short poles, 11 wall packs, and 83 downlights within the project boundaries of West Loop shopping center. The total wattage for the existing system would then be 5,858W.

Table 12 - Luminaire cutsheet data

PREVAIL (PA1B)		
TYPE V SQUARE WIDE	Power	151W
	4000K/5000K Lumens	20,332
	BUG Rating	B5-U0-G3
	Lumens Per Watt	135
	3000K Lumens	18,517

Table 13 - West loop existing fixtures

FIXTURE TYPE	WATTAGE/ FIXTURE	NUMBER OF FIXTURES	WATTAGE
Tall Poles	151W	21	3,171W
Short Poles	53W	5	265W
Wall Packs	21W	11	231W
Downlights	26.4W	83	2,191W
		TOTAL	5,858W

Glare

There is a substantial amount of glare at West Loop shopping center. The pole mounted luminaires are nearly entirely unshielded, attributing to glare in the parking lot area. Fortunately, the luminaires are short enough to avoid disability glare as well as some discomfort and even nuisance glare. Though the mounting of these fixtures avoided some glare, it didn't completely eliminate it, especially discomfort and nuisance glare. Additionally, the wall mounted and can light fixtures are similarly unshielded and closer to eye level, intensifying the opportunity for glare. Glare was discussed earlier in this paper in the Review of Design Documents and Basic Needs for Outdoor Lighting sections. Seeing as glare can occur from any bright light source in view, or even slightly outside of view, it is important to reduce causes of glare. Furthermore, glare reduction is particularly important in areas where cars will be driving near people walking to reduce accidents or injuries in addition to discomfort and distractions.

Uniformity

The uniformity of the shopping center lighting was done quite well. The parking lot is not perfectly symmetric, as can be seen in the previous maps, Figures 10, 14, 24, 30, and 34, and thus the pole mounted fixtures are not evenly spaced throughout the lot. Even with uneven spacing, the illumination of the parking lot manages to be quite uniform based on taking multiple similar readings across the entire lot. Illumination information and calculations were detailed more extensively in the quantitative analysis. The minimum of the parking lot area is 2.5 fc while the maximum is 4 fc leading to a 2.5:4 min/max ratio.

The transitional spaces mostly consist of entrance areas of buildings, namely the areas around main doors. The illumination of these areas is executed quite well in terms of avoiding discomfort when traveling between the brightly illuminated interior and the less illuminated exterior. Furthermore, these transitional areas also aid in wayfinding purposes in relation to orientation, reassurance, facial recognition, and overall atmosphere.

Safety

In a previous section the complicated relationship between safety and lighting was discussed. While this is a complicated relationship, it is important to consider how lighting design can aid or hinder the safety of West Loop. The lighting of this shopping center effectively provides proper illumination for visibility and contrast for detection of obstacles as well as recognition of irregularities of paths and faces. The entire shopping center is obviously illuminated to provide visibility and safety for those driving and walking in the area. One area that is clearly attempting to add even more illumination than the rest of the center to increase perceived security is the bank. Although, this harsh, cool-toned, additional lighting is likely not adding to the safety or security of the bank.

Design Recommendations

During the design process each of the following items should be considered and a determination made on whether it would reduce or eliminate light pollution while maintaining the needs and safety requirements of the project. Prioritizing these items starting at the beginning of the design phase will allow for a much smoother, collaborative path to an efficient and sustainable final design. These recommendations can be used both to guide individual lighting design as well as to help further the path that standards and committees are trying to pave to effectively minimize the adverse effects of light pollution.

Qualitative and Quantitative Recommendations

The following section consists of both qualitative and quantitative recommendations. These recommendations are organized similar to the quantitative and qualitative analysis sections above.

<u>Five principles of responsible outdoor lighting</u>

The five principles of responsible outdoor lighting (useful, targeted, low light levels, controlled, and color) are key to well-designed outdoor lighting. These principles form a basis of design on which more sustainable practices can be applied. These principles are discussed at length earlier in this report.

Useful

All lighting should have a clear purpose. The lighting for West Loop is a decent example of this. The pole mounted luminaires are illuminating the parking lot, the can luminaires are illuminating the pedestrian focused areas near the buildings, the wall mounted fixtures provide illumination and wayfinding for doorways. Additionally, the number and size of all luminaires should be minimized. In this case the number of can lights, especially, could be reduced. This number should be cut in half to better meet illumination recommendations as well as reduce glare. The lumen output of each luminaire could be lowered instead, however reducing the number of luminaires by half will maintain uniformity and simplify the design. Mounting heights of pole mounted luminaires throughout the project should also be examined. In this case, the mounting heights are appropriate but for a more aggressive solution the taller poles should be lowered, such as by 5 feet. This will bring the mounting height to 25 feet which will help alleviate glare and light pollution without getting close to a height that would be at risk of vandalization. The wall pack and canopy luminaires are at acceptable heights. All of these measures would aid in restoring the evening environment.

Targeted (shielding)

In addition to being useful, luminaires should be shielded. As shown in Figure 38, fixture types include: unshielded, partially shielded, or fully shielded. The most sustainable option is fully shielded and properly directed luminaires. Thus, this report recommends finding fully shielded luminaires for this project. Using shielded fixtures minimizes sky glow, uplight, light trespass, and glare. These are all key problems that sustainable lighting design aims to address. While shielding doesn’t affect cost and energy savings, it does have significant impacts on the night sky.

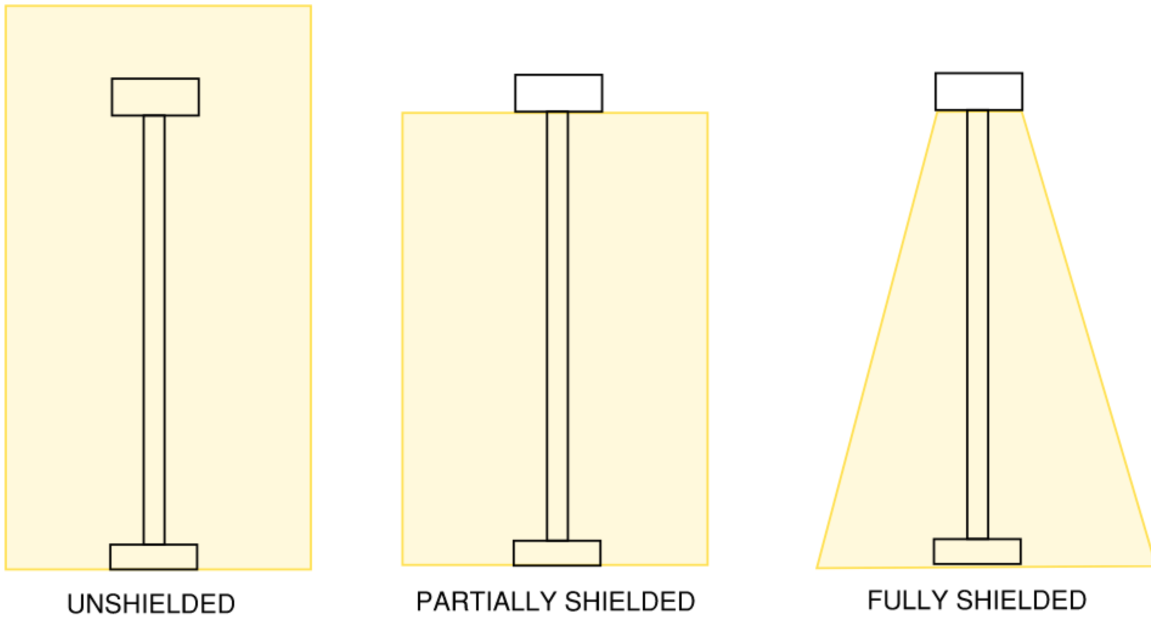

Figure 38 - Shielding fixtures

Using shielded fixtures for the pole mounted fixtures in the parking lot would give both pedestrians and cars a more comfortable experience by reducing glare while still providing adequate illumination. Furthermore, shielding fixtures near boundaries can reduce light trespass. This is particularly applicable for areas like Tommy's that are experiencing light trespass from fixtures with higher uplight and backlight that shielding could limit.

It is recommended that fixtures have as low BUG ratings as reasonable. It is difficult to make specific BUG rating recommendations because there are so many different considerations that play into that decision for each project. Not every project will be able to have B0U0G0 ratings. For a project like this, a maximum BUG rating of B2U2G2 is recommended because of the lighting zone with lower ratings applied when feasible (which is discussed earlier in this report). The below fixtures in Figure 39, for example, both have a BUG rating of B1-U0-G2. These are the luminaires selected as the recommended replacement for the cost analysis in the following section. These luminaires exceed IES recommendations of backlight and uplight, and meet those for glare. Furthermore, these luminaires are lower wattage than the current luminaires and will help meet the recommended illuminances.

Figure 39 - Low BUG rated fixtures example (Cooper, 2024).

Low light levels

Illumination levels are especially relevant with all project types; they should meet IES target recommendations, preferably on the lower side. These recommendation ranges are discussed in depth in regard to West Loop in the Data Gathering and Analysis section. As was mentioned in that section, the illumination levels of most areas of West Loop are slightly higher than the recommended value, if not significantly higher. Therefore, an even reduction in illumination across the parking lot would allow for a more sustainable design while meeting IES recommendations and without sacrificing the uniformity and contrast that was successfully accomplished in the existing installation. All of the fixtures in this space should be replaced with lower wattage fixtures to achieve this reduction. Further reduction should be done across the areas including Tommy's and the Bank that were even higher than the rest of the space, since these areas should be of similar values to the rest of the shopping center.

Controls (technology)

Before discussing the controls and technology recommendations it is worth reemphasizing the code requirements involving automatic controls. These requirements are detailed in depth in the Review of Design Documents section. These requirements include daylight shutoff, lighting setback, and time-switch controls. These code requirements should be met and even exceeded when possible. The duration and intensity at which these fixtures are on, especially when not being used, should be drastically decreased. The lighting system should only be full on during times after dark and before the retail establishments located in the center closes. It is assumed that these times are 6pm-midnight for this project. Outside of these times, full-on lighting is entirely unnecessary and wasteful. Furthermore, additional time should be utilizing dimming. From the times of 10pm-midnight for example, when the stores are mostly closed but staff may still be cleaning or locking up, advanced controls should be used to have 50% illumination or less unless motion is detected. Additionally, from the times of 6pm-8pm it isn't always completely dark, and thus 50% dimming or more should be utilized in combination with a photocell to determine necessary illumination levels. This is discussed further below.

Advanced automatic controls should be utilized in addition to code requirements to further decrease light pollution and enhance energy savings as well as functionality and adaptability. Most of the advanced controls technology discussed in the Control Considerations section, including automatic controls, sensors, artificial intelligence, and building automation systems, are primarily being utilized in indoor applications. However, these types of technology also show tremendous potential for energy savings and light pollution reduction in outdoor applications by limiting excessive illumination, uplight, and time that the fixtures are on. This report recommends utilizing these technologies as follows.

Photocells have been used with great success to automatically turn on or off lighting depending on sunlight and weather conditions. It is assumed that photocells are already being utilized in this project. Therefore, it is recommended to continue using the existing photocells to reduce cost. It is further proposed that this photocell technology be specifically used in conjunction with more advanced controls to dramatically increase savings. These advanced lighting controls utilized with photocells adapt the lighting in an area to the usage and conditions of the space. This kind of infrastructure can be integrated with communication technology, signage, CCTV, speakers, and other kinds of systems (Global, 2020).

It is also recommended that motion sensors be utilized in the manner discussed in the Control Considerations section. Furthermore, there are artificial intelligence tools that are being developed that can distinguish between people, cars, and animals. Using these tools in tandem with the current sensor technology can fundamentally change the way that we light, and conversely dim, outdoor luminaires. Utilizing this ability to distinguish different types of movement is important because each type of movement has different illumination needs. The illumination needs for a car are going to be greater than the needs for a pedestrian. Previously, the industry shied away from using motion sensors in exterior lighting systems because any small movement, like that of an animal, would trigger a full-on command. With the blend of these two technologies, the system would be able to detect an animal and not react, detect a car and fully illuminate the space, and detect a person and partially illuminate the area. This greatly increases the ability to have exterior spaces be on more of a standby-off than an unnecessary always-on. This technology would override the scheduled off during late night hours, so as to provide safe illumination if a car or person were detected.

Moreover, it is proposed that integration with interior building automation systems be considered and further researched. These systems are rarely utilized in outdoor applications despite their prevalence in indoor applications. As discussed previously, using the already existing technology and applying it to outdoor systems will provide another solution to pollution of the night sky by controlling the way the light is emitted and utilized. In an application like West Loop centralized control becomes a potential problem. These kinds of areas with multiple businesses and tenants create additional obstacles that a stand alone business doesn't face regarding a building automation system. This is especially true when each tenant owns or pays for their portion of the lighting system instead of an owner having ownership of the whole system and then charging the tenants based on use. While it will look different for each project, integration of building automation systems has a lot of potential and should be considered.

Color

Ideal correlated color temperature (CCT) levels vary by time of day but there are still standard methods that determine the recommended ranges. These methods and levels are detailed further in the Review of Design Documents section. The goal for designers is to pick a source near the middle of the spectrum for optimum human comfort and satisfaction. Furthermore, there are certain CCT levels that are commonly used with specific intent to promote health, comfort, and productivity. This paper therefore recommends 3000K luminaires.

<u>Luminaires and wattage</u>

Using more efficient luminaires on a project is one of the main ways to drastically impact energy usage. This also has the ability to offset the cost of lighting and control improvements with energy savings. Low wattage fixtures should be utilized whenever possible. These fixtures often have a higher first cost but make up for that price difference by saving a drastic amount of money in decreased energy use. A cost analysis is detailed in the section below. Furthermore, as discussed in the Review of Codes and Standards section, there are limitations to the allowed connected power when adopted into code in the local jurisdiction.

Since the fixtures in this project are assumed to be LED, it is less relevant that a lower wattage replacement be found to lower energy usage and expense because they are likely already fairly low wattage. Finding an even lower wattage equivalent would simply result in a more drastic result than keeping the current LED sources. The can lights, wall mounted fixtures, canopy lights, and LED strips should all be low wattage. Example recommendations can be found in the cost analysis below.

Cost Analysis

It is relevant to discuss the financial incentive for clients to proceed with this kind of large change. This cost analysis is based on kilowatt hour estimates and does not include demand charges. The luminaires for this project are assumed to already be LED, however, there were additional recommendations, as were discussed above. The following cost analysis walks through what these changes entail, the associated costs, and a simple payback calculation. The assumed conditions are stated below. As a simplified payback calculation, this cost analysis is not all encompassing, but it gives a good indication of the feasibility of this kind of change. The cost analysis for this project would be a retrofit seeing as there is already an existing lighting system at West Loop, but a similar process should be followed for new projects as well. This cost analysis is provided in this report so as to further show the applicability of a project like West Loop.

Current Wattage

The current wattage for tall poles is 151W and for short poles 53W. Furthermore, the wall packs are 21W and the downlights are to be 26.4W. There are 21 tall poles, 5 short poles, 11 wall packs, and 83 downlights within the project boundaries of West Loop shopping center. This totals to 5,858W. The existing lighting is on from dusk to dawn, which is roughly 6pm to 6am or a total of 12 hours. The kilowatt hours would then equal 5858W*12hrs = 70,296Wh*1kW/1000W = 70.3kWh. The energy rate is $0.10 per kWh. The current annual cost is thus assumed to be 70.3kWh*$0.10 = $7.03*365 days = $2,565.95 per year.

Recommended Wattage

The recommended replacement luminaires for this project are all LED 3000K low wattage alternatives. The wattage for lowered tall poles (Figure 40) is 74W and for short poles (Figure 40) is 31W. Furthermore, the wall packs (Figure 41) are 14W and the downlights (Figure 42) are 10.7W. These fixtures are to be replaced one for one for the purposes of this report for simplicity's sake, except for the downlights which are cut in half, due to excessive illumination as was discussed earlier in this report. Thus, the total wattage would be 21tall pole fixtures*74W+5 short pole fixtures*31W+11 wall pack fixtures*14W+40 down light fixtures*10.7W = 2,291W.

Figure 40 - Example LED pole mounted (Cooper, 2024).

Figure 41 - Example LED wall mounted (Cooper, 2024).

Figure 42 - Example LED downlight (Cooper, 2024).

The new lighting system would only be on from 6pm to midnight as per ASHRAE 90.1-2022 which is detailed further in the Review of Codes & Standards section. This totals to 6 hours of usage. The kilowatt hours would thus be 2291W*6hrs = 13746Wh*1kW/1000W = 13.75 kWh. The Evergy energy rate is $0.10 per kWh. The annual cost for the recommended system is thus calculated to be 13.75kWh*$0.10 = $1.375*365 days = $502 per year. This would therefore result in a savings of $2,064 each year compared to the current yearly cost.

<u>Costs associated</u>

Furthermore, the costs associated with this change were calculated and presented in Table 13 below. The 2024 costs associated with labor and demolition were estimated from RS Means with costs totaling $5,356. The costs of the new LED fixtures were provided from a local representative at Mercer Zimmerman, Kate Wimer on September 9th, 2024. These estimated fixture costs total $34,700. The cost associated with the new lighting controls, described in the Recommendations section, is $25,000. These costs were then summed, and an additional forty percent was added for contractor markup and overhead and twenty percent was added for profit. The total cost of this change would thus be $104,089.60.

Table 14 - Costs associated

LABOR / DEMO				
Luminaires	Wattage	# of Fixtures	Cost of Fixtures	Subtotals
Tall Poles	151W	21	$53.50	$1,123.50
Short Poles	53W	5	$47.50	$237.50
Wall Packs	21W	11	$42.50	$467.50
Downlights	26.4W	83	$42.50	$3,527.50
			Total:	$5,356
NEW FIXTURES				
Tall Poles	74W	21	$750	$15,750
Short Poles	31W	5	$750	$3,750
Wall Packs	14W	11	$200	$2,200
Downlights	10.7W	40	$325	$13,000
			Total:	$34,700

Simple payback calculation

In addition to calculating the costs associated with a project, a simple payback calculation should be utilized in order to determine how long it will take to pay for the recommended modifications. This kind of calculation aids in determining the feasibility of a project. In general, lamp life is considered to be 40,000 hours, which divided by (12hrs*365days) equates to 9.1 years. This means that lamps need to be replaced less than every ten years. Five to ten years is a reasonable range, but anything over ten years begins to exceed the expected life of light sources. At that point additional maintenance costs would be incurred. Thus, a project is most feasible when the payback is below that 10 year mark.

Simple payback is calculated by dividing the initial cost by the yearly savings. Thus, for this project the yearly payback would be $104,089.60/$2,064, resulting in roughly 50 years. This is obviously well above the ten-year threshold. This high number results from the somewhat recent upgrade of lighting serving the West Loop shopping center from HID fixtures to LED fixtures. The upgrade reduced the wattage, but not to the level recommended in this report. Additionally, though the fixtures became more energy efficient, they did not adequately address night sky issues, leading to the changes currently needing to be made.

Follow-up payback calculation

The following calculation is provided to show what the payback would have been from HID to the proposed design without the intermediate LED renovation. The cost of demolition of HID fixtures would have been $29,217, as shown in Table 14. This demo cost is different to that of the first calculation due to the difference in cost of demolishing HID vs LED luminaires. The new fixtures would still cost $34,700 and the controls would still be $25,000. Add on the same forty and twenty percent multipliers results in a total cost of $88,917. The HID annual cost would be 17010W*12hrs = 204,120Wh/1000 = 204.12 kWh multiplied by the Evergy energy rate of $0.10 per kWh. Equaling 204.12kWh*$0.10 = $20.412*365 = $7,450.38 per year. The new annual cost would be the same $502 as above.

Table 15 - HID labor/demo costs

HID LABOR/DEMO				
Tall Poles	400W	21	$194	$8,148
Short Poles	175W	5	$213	$2,130
Wall Packs	175W	11	$53.5	$1,177
Downlights	70W	83	$107	$17,762
			TOTAL:	$29,217

The simple payback would then be $88,917/($7,450.38-$502) = 12.8 years. This calculation is still higher than it likely would be because it is hard to estimate the additional cost and energy savings from dimming. Taking some additional assumptions into account based on the recommendations above, the lights would only be on full for 2 hours and on 50% for the other 4. Assuming the cost for the lighting controls would be the same as before, the kilowatt hours would then be 2291W*2hrs+2291W*(4hrs*50%) = 9,164Wh*1kW/1000W = 9.16kWh*$0.10 = $0.916*365 days = $334.34. The simple payback would then be $88,917/($7,450.38-$334.34) = 12.5 years. This is still above the ten-year threshold but is more realistic.

While this new simple payback is still 12.5 years, it is much lower than the 50 years that it would be from LED to the proposed design. This calculation was provided to show the importance of implementing these recommendations at the right time as well as to show that if this design had been proposed at that time it would have been more feasible to convince the client to move forward with these recommendations than it would be currently. This decrease in length of payback time as well as the drastic improvements on the night sky showcase the importance and viability of the recommendations proposed in this report. It will still be important to make sure the client is aware of the sustainability impacts related to making a decision that extends beyond a financial return.

This cost analysis is a simplified version of what a client would want in order to analyze whether the system updates would make sense financially for them. A detailed life cycle analysis would be recommended for that kind of application. The above simplified analysis is included in order to show that these renovations are feasible and worthwhile as incentive for clients to proceed with a more detailed discussion and analysis. The threshold of viable further pursuit will vary from client to client. It will be important to educate the client on all of the factors that influence a project, beyond just the economic impacts.

Conclusion

Artificial lighting at night threatens how we perceive and interact with the outdoor environment and negatively impacts plants, animals, and humans. The endeavor to implement sustainable practices within lighting design reduces energy consumption, mitigate light pollution, and aid in effectively restoring the night. This report aimed to analyze the outdoor lighting industry and explore the need for sustainable exterior lighting design.

This report urges the push toward increasingly progressive codes and standards as well as prioritizing the implementation of these recommendations on more local levels. Implementing these changes into code will be difficult to accomplish with the leading sustainability codes being entirely focused on energy savings. Thus, it will be important to push for recognition of these topics and their importance via ordinances that will have large impacts on both smaller and larger municipalities.

This report firstly recommends continuing to implement current sustainable outdoor lighting design methods. This includes minimizing illumination levels, only lighting necessary areas, providing shielded luminaires, limiting uplight and glare, using low-wattage light sources, and taking color temperature into account. These practices have proven positive results. This report also finds that technology is constantly evolving in ways that continue to be more applicable and efficient in outdoor lighting systems. The technologies that are most promising include smart lighting controls, daylight sensors, motion sensors, artificial intelligence, and integration with indoor building systems, as well as the combination of multiple or all of these technologies in one system for maximized results. Oftentimes these tools have been created with indoor applications in mind but looking forward, they also show great potential for similar outdoor applications and will continue advancing and improving. The implementation of these recommendations will aid in reducing light pollution and restore some semblance of natural darkness at night. These measures also result in energy savings as an opportunity to offset new lighting system costs in a short period of time.

This report then analyzes an existing outdoor lighting system in Manhattan, KS. Quantitative and qualitative analyses are discussed. Then design recommendations were presented. Finally, a cost analysis and simple payback calculation were developed. This payback analysis was higher than originally anticipated; however, it was shown that if proposed at the right time, these recommendations can reasonably be shown to the client as incentive to better protect the night sky.

In addition to the recommendations presented in this report, it urges the continued research and development of other emerging technologies and practices. As president of Augmented Illumination, Mark Lien, LC, LEED AP, asserts, “Your customers should know that you understand where the future of lighting is headed, or they will be reluctant to let you lead them there” (Lien, 2023).

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Appendix A - Tables

Table A.1 - Individual Lighting Power Illuminances for Exteriors (ASHRAE, 2022).

Table A 1 - Individual Lighting Power Illuminances for Exteriors (ASHRAE, 2022).

Table 9.4.2-2 Individual Lighting Power Allowances for Building Exteriors Applications

	Zone 0	Zone 1	Zone 2	Zone 3	Zone 4	Section 9.4.1.4 Required Controls
Base Site Allowance (Base allowance may be used in tradable or non-tradable surfaces.)						
	No allowance	160 W	280 W	400 W	560 W	
Tradable Surfaces (*LPD* for uncovered parking areas, *building* grounds, *building entrances*, exits and loading docks, canopies and overhangs, and outdoor sales areas may be traded.)						
Uncovered Parking Areas						
Parking areas and drives	No allowance	0.015 W/ft^2	0.026W/ft^2	0.037 W/ft^2	0.052 W/ft^2	(b) and either (d) or (e)
Parking areas and drives with *luminaires* >78W and mounting height <24 ft	No allowance	0.015 W/ft^2	0.026 W/ft^2	0.037 W/ft^2	0.052 W/ft^2	(b) and (e)
Grounds						
Walkways/ramps	No allowance	0.5 W/linear ft	0.5 W/linear ft	0.55W/linear ft	0.60 W/linear ft	(b) and either (d) or (e)
Plaza areas	No allowance	0.028 W/ft^2	0.049 W/ft^2	0.070 W/ft^2	0.098 W/ft^2	(b) and either (d) or (e)
Roof terraces and special features	No allowance	0.04 W/ft^2	0.07 W/ft^2	0.10 W/ft^2	0.140 W/ft^2	(b) and either (d) or (e)
Dining areas	No allowance	0.156 W/ft^2	0.273 W/ft^2	0.390 W/ft^2	0.546 W/ft^2	(b) and either (d) or (e)
Pedestrian tunnels	No allowance	0.063 W/ft^2	0.110 W/ft^2	0.157 W/ft^2	0.220 W/ft^2	(d) or (e)
Landscaping	No allowance	0.014 W/ft^2	0.025 W/ft^2	0.036 W/ft^2	0.050 W/ft^2	(b) and (c)
Building Entrances, Exits, and Loading Docks						
Pedestrian and vehicular entrances and exits	No allowance	5.6 W/linear ft of opening	9.8W/linear ft of opening	14.0 W/linear ft of opening	19.6 W/linear ft of opening	(b) and either (d) or (e)
Entry canopies	No allowance	0.072 W/ft^2	0.126 W/ft^2	0.180 W/ft^2	0.252 W/ft^2	(b) and either (d) or (e)
Loading docks	No allowance	0.104 W/ft^2	0.182 W/ft^2	0.260 W/ft^2	0.364 W/ft^2	(b) and either (d) or (e)
Sales Canopies						
Free standing and attached	No allowance	0.20 W/ft^2	0.35 W/ft^2	0.50 W/ft^2	0.70 W/ft^2	(b) and either (d) or (e)
Outdoor Sales						
Open areas (including vehicle sales lots)	No allowance	0.072 W/ft^2	0.126 W/ft^2	0.180 W/ft^2	0.252 W/ft^2	(b) and either (d) or (e)
Street frontage for vehicle sales lots in addition to "open area" allowance	No allowance	No allowance	7.2 W/linear ft	10.3 W/linear ft	14.4 W/linear ft	(b) and either (d) or (e)
Nontradable Surfaces (*LPD* for the following applications can be used only for the specific application and cannot be traded between surfaces or with other exterior lighting. The following allowances are in addition to any allowance otherwise permitted in the "Tradable Surfaces" section of this table.)						
Stairways	Exempt	Exempt	Exempt	Exempt	Exempt	(b)

Table A.1 *continued* - Individual Lighting Power Illuminances for Exteriors (ASHRAE, 2022)

Table 9.4.2-2 Individual Lighting Power Allowances for Building Exteriors Applications *(Continued)*

	Zone 0	Zone 1	Zone 2	Zone 3	Zone 4	Section 9.4.1.4 Required Controls
Building facades (The allowance for each illuminated facade *orientation* shall be calculated by multiplying the allowable value by the entire *facade area* or facades length for that *orientation*.)	No allowance	0.056 /ft^2 of *facade area* or 1.4 W/linear ft of facade length	0.098 W/ft^2 of *facade area* or 2.4 W/linear ft of facade length	0.140 W/ft^2 of *facade area* or 3.4 W/ linear ft of facade length	0.196 W/ft^2 of *facade area* or 4.8 W/linear ft of facade length	(b) and (c)
Automated teller machines and night depositories	No allowance	90 W per location plus 35 W per additional ATM per location	90 W per location plus 35 W per additional ATM per location	90 W per location plus 35 W per additional ATM per location	90 W per location plus 35 W per additional ATM per location	(b)
Uncovered entrances and gatehouse inspection stations at guarded facilities	No allowance	0.144 W/ft^2	0.252 W/ft^2	0.360 W/ft^2	0.504 W/ft^2	(b) and either (d) or (e)
Uncovered loading areas for law enforcement, fire, ambulance, and other emergency service vehicles	No allowance	0.104 W/ft^2	0.182 W/ft^2	0.260 W/ft^2	0.364 W/ft^2	(b) and either (d) or (e)
Drive-through windows/doors	No allowance	53 W per drive-through	92 W per drive-through	132 W per drive-through	185 W per drive-through	(b) and either (d) or (e)
Parking near 24-hour retail entrances	No allowance	80 W per main entry	140 W per main entry	200 W per main entry	280 W per main entry	(b) and either (d) or (e)
For areas that are not listed in this table or are not comparable to areas listed in this table, use the comparable interior *space* type from Tables 9.5.2.1-1 and 9.5.2.1-2 as modified by factors in this row.	No allowance	22% of the *interior lighting power allowance* value	39% of the *interior lighting power allowance* value	55% of the *interior lighting power allowance* value	77% of the *interior lighting power allowance* value	(b) and either (d) or (e)
Roadway/parking entry, trail head, and toilet facility, or other locations approved by the *authority having jurisdiction*.	A single *luminaire* of 10 W or less	No additional allowance	No additional allowance	No additional allowance	No additional allowance	(b) and either (d) or (e)

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Karen

Karen Brodie (she/her)

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System Leadership
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Muratova Zulfizar
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