

Glare Pollution from Building Facades and its Effects on the Visual Comfort of the Surrounding Environment: The case of Selected Buildings in Addis Ababa City



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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA - Analysis of variance
ARC - Anti-reflective coating
CCM - Computational continuum Mechanics
CFD - Computational fluid dynamics
GlareD – Glare Duration
GlareS – Glare Sensitivity
GlareT - Glare Time
HD - Horizontal Distance
HDR - High Dynamic Range
HDRI- High Dynamic Range Imaging
MoE – Margin of Error
NOC – National oil Company
SC - Share Company
SHGC- Solar heat Gain coefficient
SPSS - Statistical package for the social Sciences
VD- Vertical Distance

ABSTRACT

In recent years, highly reflective materials have been widely used in the building envelope not only for aesthetic reasons but also to reduce energy consumption and improve occupant satisfaction. The use of highly reflective materials in combination with curved building designs can harm the environment. This problem can cause thermal and visual discomfort for drivers, pedestrians, and occupants of nearby buildings, and it can cause vegetation damage. Hence, this study aims to assess the impact of reflected glare from the reflective building facade on the visual comfort of drivers, nearby residents, and pedestrians. For drivers' and nearby residents' visual comfort assessments, a geometrical approach was adapted. For pedestrians' glare assessment the relationship between pedestrians and reflected glare issues is determined by using a survey. For drivers, by using Holladay's veiling glare formula, the veiling glare from the facade of the building was calculated at a different point. For nearby residents, based on the Sydney City Council of buildings standard the reflected glare was assessed in the nearby occupants from the sample building. For drivers, the maximum calculated veiling glare is 413.19 cd/m^2 which glare is unlikely for drivers' comfort. For nearby residents, according to the standard, the reflected sunlight to the neighboring buildings must not exceed 20% of incident sunlight. However, the reflected sunlight exceeds 47.64% which is greater than the allowable limit so there is reflected glare pollution in the neighborhood buildings occupants. For pedestrians, the subjective assessment was done by using questioner. Building glare significantly affects the glare sensitivity of pedestrians. Age has 35%, glare adaptation has 32 %, glare time has 13 %, and glare duration has a 10 % effect on the glare sensitivity outcome of the pedestrians.

Keywords: Glare pollution, Solar reflectivity, Outdoor glare, Visual comfort

CHAPTER ONE

1. INTRODUCTION

The study aimed to investigate the effects of glare pollution from the building facades in the visual comfort of the surrounding environment in Addis Ababa Ethiopia. Addis Ababa is a rapidly growing city, numerous buildings have been constructed and are under construction. Those buildings use highly reflective materials for envelopes. Therefore, the use of reflective materials as a building facade can lead to indoor and outdoor glare.

Therefore, analyzing the effect of building glare on outdoor visual quality is crucial. However, there is a lack of research on the effect of outdoor building solar reflection on the visual comfort of nearby residents', drivers and pedestrians. But Visual comfort is one of the criteria for sustainable building for the outdoor and indoor environment.

Above that, the other motivation for doing this study was the researcher experiencing visual discomfort on the road due to uncontrolled solar reflection that bounces off from the buildings' envelopes, especially in the central business districts of Addis Ababa. That is the main reason to conduct a study in the Administrative city of Addis Ababa, Ethiopia.

1.1. Background of the study

Buildings can influence the surrounding microclimate with their facade design. Reflective surfaces from the building envelope can reflect daylight into the vicinity and cause problems such as glare and overheating (Suk et al., 2017a). In the last decade, an increasing number of cases of solar reflectivity have emerged due to the rise of geometrically complex buildings and the wide use of reflective surfaces on the skin of the building (Suk et al., 2017a).

Designers use highly reflective materials as building envelopes because of design purposes, to increase the commercial value of large-scale buildings, and to achieve the goal of saving energy and reducing the cooling load (M. Schiler & Valmont, 2005).

External glare occurs mainly from curved or vertically inclined facades with highly reflective building materials. Reflective materials on curved surfaces can amplify sunlight in the same way that solar concentrators do and cause more trouble. The sunlight reflected from the facades can disturb drivers, pedestrians, and residents and under certain circumstances, it can lead to impaired vision

(Yang et al., 2013). But, insufficient concerns are being raised about the noticeable and pervasive effects of solar reflections from buildings on the outside world and the general public.

When direct sunlight bounces off a reflective facade of a building at an angle to intercept of viewer's eye, it can be perceived as a source of high luminance glare (Mehaoued & Lartigue, 2019). Glare pollution appears when the brightness variations in the visual field are too great; the brightest area becomes a source of glare. When the brightness ratio is extremely high, the glare conditions will impair our ability to see any details near the immediate vicinity of the glare area (Pohl, 2011).

In developed countries, there are regulations regarding solar reflectivity (EA Engineering Science and Technology Inc., 2017), the building code that had been regulated by the department of the built environment in the city of London and enforced since 2017, and the code mitigation techniques such as reducing the area of glazed surfaces, using low reflectance films or using external shading devices are listed.

In Ethiopia, there are no industry-wide accepted regulations concerning solar reflections in the built environment. Generally, there is a lack of regulations regarding solar reflectivity in the building codes of developing countries.

1.2. Statements of the problem

Highly reflective building envelopes are being employed more frequently in Addis Ababa lately for a variety of reasons, including lowering building costs, lowering energy consumption, and raising occupant comfort levels concerning the building's heating and cooling, ventilation, and lighting. According to the researcher's observation in Addis Ababa, buildings that are oriented west and southwest, highly glazed, and medium and high-rise buildings reflect sunlight on the nearby environment. However, these reflective materials contribute to an increasing number of comments associated with the reflected outdoor glare problem. This uncontrolled reflection cause glare and glare effects are seriously impacting the environment, by damaging entire ecosystems. (Ishak et al., 2019) In Ethiopia, there are no standards and regulations concerning solar reflections in the built

environment. However, high-rise buildings and curved facades need adequate design consideration regarding solar reflectivity.

Therefore, these existing glare problems affect people's visual comfort. Glare can cause temporary blindness where one's central and peripheral vision is blocked or washed out by the brightness and road safety problems as bright or poorly shielded light sources in the street area can unexpectedly partially dazzle drivers or pedestrians and contribute to traffic accidents. Glare can cause irritation, eye strain, and overall discomfort to the eyes. Reflective glare influences not only the visual system, but also numerous non-visual effects such as physical, mental, and behavioral changes.

According to (Ababa, 2016) in Addis Ababa outdoor glare pollution was shallowly studied in some buildings but the study is mainly focused on the effects of glare inside the building. And, less attention has been paid to external glare. This study deals with glare pollution from building facades and its effects on the visual comfort of the surrounding environment.

1.3.Objectives

1.3.1. General objective

The general objective of the study is to investigate the effects of glare pollution from the building facades on the visual comfort of the surrounding environment in Addis Ababa city.

1.3.2. Specific objective

The specific objectives are:

- To assess the impact of reflective building facades on drivers' visual comfort
- To assess the impact of the reflective façade on the neighboring residents' visual comfort
- To assess the impact of the reflective façade on the pedestrian's visual comfort

1.4.Research Questions

1. What is the impact of a reflective building facade on drivers' visual comfort?
2. What is the impact of the reflective building façade on the neighboring residents?
3. What is the impact of the reflective building façade on the pedestrians' visual comfort?

1.5. Significance of the study

The research mainly focuses on understanding how drivers' nearby occupants and pedestrian perceives and handle building glare issues.

For Architects

The study was crucial for designers to investigate and explain the impact of building envelopes as a design variable on the outdoor visual quality. This will be useful to architects in determining the importance of outdoor visual comfort in design decisions.

For government

It is hoped that the findings of this study benefit and create more awareness for Addis Ababa city Administration, and other organizations dealing with the outdoor visual quality of the built environments.

For researchers

This study will have significance as an academic input and to improve the visual comfort in the outdoor environment. The study could be used as a starting point for local research on outdoor glare pollution. It allows other researchers to investigate the current gap in overcoming the impact of reflective facades in greater depth. In general, it helps to develop a strong understanding of the impact of solar reflections on the built environment. Therefore, it will encourage researchers to do additional research in the field.

1.6. Scope of the study

The thematic area of the study focuses on the solar reflectivity of glass façades on visual comfort. For drivers and nearby resident's solar luminance level measurements were taken. For pedestrian visual satisfaction subjective assessments were applied.

Spatially this study is conducted in to five purposively selected buildings in Addis Ababa, These are respectively Awash bank and insurance Sc. at kirkos sub-city on Ras Abebe Aregay Street, Churchill hotel is located at Arada sub city on Churchill Avenue, National oil Ethiopia located at Bole sub city Africa Avenue, Eshetu Mamo commercial center located at Arada sub city on Churchill Avenue, and Dirar mall is located in Yeka sub city Mariam road in the city of Addis Ababa.

1.7.Limitation

The data collection for the driver's comfort ability state was challenging due to the traffic flow of the vehicles. so, that the data was collected only in one day, the other limitation was the study thematic area lacks reference documents for outdoor glare issues on the building facades in the Ethiopian context.

1.8. Operational definitions

Visual comfort: The criteria are based on the amount of light, the contrast balance, the color' temperature,' and the presence or absence of glare in the visual field. (Pohl, 2011)

Glare: Excessive brightness in the visual filed and depending on the degree may produce discomfort or visual disability. (Emmit and Gorse, 2010).

The location of the glare source relative to the observer: The offending light source will be much more annoying if it is directly in the line of sight rather than just visible through the corner of the eyes. (Pohl, 2011)

The luminance of the glare source: The size of the glare source, which is typically an artificial light source in the form of a lamp, is also a consideration. If the light flux is spread over a larger surface area, the brightness of the immediate surroundings will tend to increase. (Pohl, 2011)

The general background illumination level: Quantified as the Adaptation Level, which is defined as the average luminance of all surfaces in the visual field. (Pohl, 2011)

Disability Glare: Impairs our immediate visual performance. (Pohl, 2011)

Discomfort glare: Occurs quite frequently in artificially lit building spaces if light sources are inadequately shielded. (Pohl, 2011)

Veiling glare: A type of disability glare that refers to the optical image degradation caused by light scattered across the retina from a bright source. (Gil, 2016)

Equivalent veiling luminance: The ratio between solar illuminance at the angle of the observer to the glare source angle (Gil, 2016)

Glare source intensity: The direct illuminance reaching the observer's eye from the glare source (Gil, 2016)

Observer's sensitivity (K); The sensitivity factor (k) takes into account the age of an observer, (Gil, 2016)

The eye's focal sensitivity(n): The sensitivity factor (n) represents how rapidly equivalent veiling luminance responds to reductions in the glare angle (Gil, 2016)

Glare angle (θ): the glare angle between the observer's line of sight to the source of glare(Gil, 2016)

Driver's adaptation state: The amount of background light the retina receives under static conditions. (Gil, 2016)

Reflection: Which happens when light strikes a polished surface and is reflected away from it so that the angle of incidence equals the angle of reflection(Montes-Amoros, 2015).

The reflectance of a surface: The percentage of light incident on the surface that is reflected from the surface(Montes-Amoros, 2015).

Illuminance: The amount of light flux falling on a surface area is measured in lumens per square foot or footcandles (Pohl, 2011)

Luminance: The intensity per unit area of a surface as seen from a specific direction, measured in candela/surface area or foot-lamberts (fL). (Pohl, 2011)

Glare Sensitivity is a debilitating loss of visual acuity in bright lighting. (van den Berg et al., 2009)

1.9.Organization of the paper

The thesis consists of five chapters.

In the first chapter, the introduction, background of the study, research problem definition objectives, significance of the study, the scope of the study, limitation, and operational definition of the study are explained.

In the second chapter, the literature review presented consists of the theoretical and empirical literature were presented. In the theoretical review section, solar reflectivity and its negative impact, glare, how buildings can be a source of glare, glare nuisance for drivers, pedestrians, and neighboring buildings, objective measurement of different outdoor glare estimation methods, subjective human perception of glare, human sensitivity of glare, and glare mitigation techniques are explained. In the empirical review section, the rules and regulations and standards of outdoor glare issues in different cities were presented.

In the third chapter, the material and methods of the study are presented. The materials that helped to conduct a study are listed and the method that was carried out throughout the research is explained in detail.

In the fourth chapter, results and discussion are presented in detail. The analysis and results that were conducted from the objective assessment of glare for drivers and nearby occupants as well as the subjective assessment from human perception are presented.

In the final chapter, the conclusion derived from the previous chapters is summarized and the recommendations for future studies are mentioned.

CHAPTER TWO

2. LITERATURE REVIEW

The literature review has been carried out by searching online scientific journals and databases. The review starts with theoretical backgrounds, which include similar works at the international level, and an empirical review to provide an answer to a specific research topic. The works of literature were searched and filtered based on some keywords such as solar reflection, glare pollution, outdoor glare, and visual comfort.

2.1. Theoretical Literature review

2.1.1. Solar reflectivity

To understand the basic principles of solar reflection, one should be familiar with the optical laws of reflection that occur on various surfaces such as flat or curved and opaque or transparent. With transparent surfaces, some of the light transmitted through the medium is reflected and the rest is reflected, as can be seen in figure 2.1(Montes-Amoros, 2015).

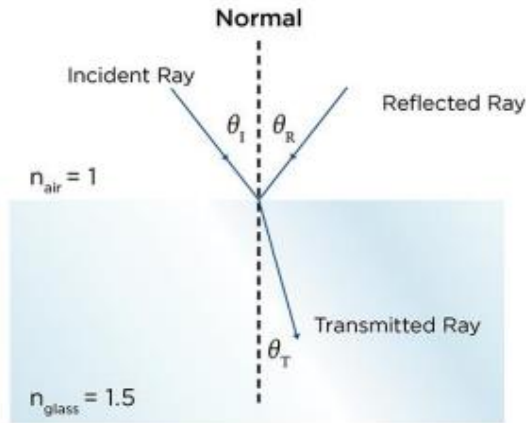


Figure 2.1: Diagram of reflection law on glass

According to (Danks et al., 2016a) when light travels through one medium and meets another, it exhibits different behaviors. The surface of the medium determines the light distribution. When the light is reflected in one direction it is called specular reflection, and when it is scattered into the former medium it is called diffuse reflection, as seen in figure 2.2.

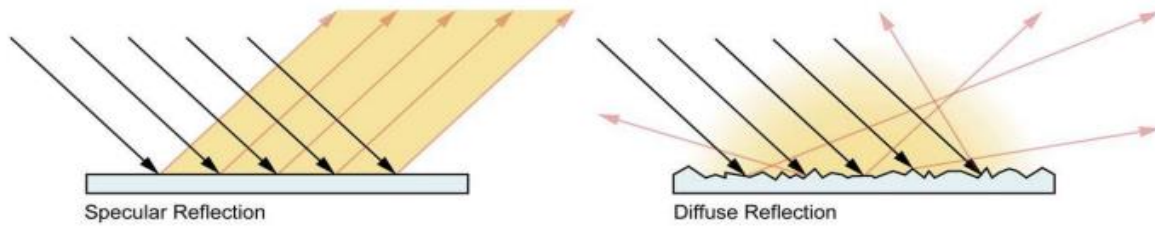


Figure 2.2: A diagram of how light reflects through different surfaces

While rough and matte surfaces scatter light in different directions, preventing light rays from merging to a specific point, smooth and shiny surfaces reflect light in a single direction at the same angle at which they hit the surface, creating the light converging at the same angle will area and retain much of its energy. This type of reflection is the main focus of this research because it causes undesirable environmental influences such as glare and thermal stress on the environment (Danks et al., 2016a)

2.1.2. Glare

Glare is a vision condition in which there is significant discomfort or reduction in the ability to see objects, or both, due to an inappropriate distribution or range of luminance, or extreme contrast in space, or time (Emmit and Gorse, 2010). It is a serious form of light pollution caused by excessive brightness which can make a person blind. The extent of brightness or graininess is depended on different situations like the direction of the glare, the physiological status, and the age of a person (Tashiro et al., 2014).

Glare is a significant problem in warm and hot climates, both inside buildings and in the surrounding environment. Building materials have been increasingly sophisticated at rejecting or even selectively filtering radiant gain, but the by-product has sometimes been an increase in the negative impact on surrounding buildings, traffic, and outdoor environments. This difficulty may be referred to as thermal and visual glare. It is true, even in cool and cold climates, especially in urban areas(M. E. Schiler, 2000).

The eye is capable of adapting to a large range of luminance this is called an adaptation of glare, however, it takes time, and once the eye is adapted, Objects that are brighter result in glare. When the

object luminance is too high or too low in comparison to the adaptation luminance, visual performance suffers.

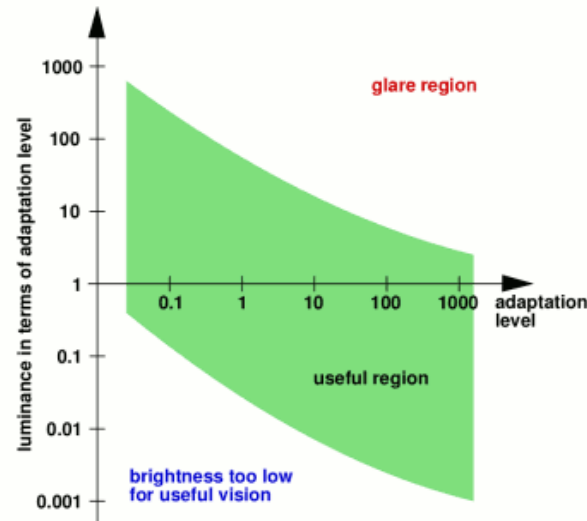


Figure 2.3: The object luminance and Glare adaptation level (Jacobs et al., 2005)

Based on the effect on people Glare has been divided into two categories: disability glare and discomfort glare. Disability Glare occurs when the luminance of the glare source is significantly higher. This causes the eye's adaptation level to rise, it can decrease eyesight. When this happens we say there is some glare from a disability. But, glare from discomfort can be present without obstruction, If the glare sources are not too bright, they are merely annoying and do not interfere with vision directly. This is known as discomfort glare. Little or no disability may be caused, but the severity of the discomfort can be most pronounced. (Jacobs et al., 2005)

Another approach to glare classification is based on the cause of the glare sensation or the subjective measure of direct glare and indirect glare. The direct glare is the one that directly impacts the view when the eye comes in contact with the primary source of light, which generates the glare effect. Light sources such as candles, artificial light fittings, or windows cause direct glare. A light source is not visible to the observer, highly reflective or glossy objects can produce bright splotches that act as indirect sources this is called indirect glare. (Gelan, 2012)

2.1.3. Sources of Glare

(Gelan, 2012) stated that, Glare is caused by light that is spilled from luminaries in any direction to cause discomfort, distraction, or inability to properly see what the light is supposed to be illuminating. Direct glare is caused by the lighting system and is defined as excessive light misdirected toward the eye. Usually, the uncontrolled luminance of an exposed light source produces glare. Direct glare refers to both the afternoon sun and the electric illumination, as the sources of glare. Light sources such as candles, artificial light fittings, or windows cause direct glare.

The reflected glare, as its name implies, refers to the light spread on different materials, which possess reflective properties reflective glare is excessive uncontrolled luminance reflected from objects or surfaces in the field of view. This includes the reflected luminance from interior surfaces as well as the luminance of the lighting system.” (Gelan, 2012 cited in Gordon, 2003).

The light source is reflected in specular surfaces, generating their mirrored images in the specular surfaces. Specular surfaces produce the reflected glare effect since they produce the mirrored image of the sources of light. These materials prevent highlights because they are uniformly bright from all angles. The reflected image of the illuminating sources can be both diffuse and specular, the differences between these two forms of light reflection. Diffuse reflectance is dependent on the quantity of illuminance on the surfaces. Specular reflectance is dependent on the source of the reflected image of the lamp or luminaire. This causes a veiling image on the work surface that obscures surface detail. (Gelan, 2012 cited in Gordon, 2003).

2.1.4. Negative impacts of solar reflectivity

The light rays reflected by reflective facades have a variety of effects on the environment and the viewer. These effects can have a variety of consequences, ranging from fatal to negligible. As (Naai Jung Shih & Huang, 2001) state, the effects of sun reflection can be analyzed in three different categories, such as high speed, medium speed, and slow speed, based on the relative movement of the observer. At high speed, drivers exposed to reflective glare can put themselves or others at risk of fatality. Moderate speed explains the pedestrian-related impact. After all, the most constant effect of reflective glare, which occurs at slow speeds, is between the source of the glare and the neighboring buildings and vegetation that are permanently in the area of the reflection location. Further analysis of the effects shows that they are divided into two categories according to the possibility of instantaneous or constant effects.

2.1.5. Buildings and solar reflection

The height of the buildings and their facade should be taken into account. These are some factors that contribute to glare pollution orientation building, the geometry of the building, the finishing material of the building, the location of the sun, the location of the observer, and the angle of reflection. (Danks & Good, 2016)

The geometry of the building and the form of the facade have a direct influence on the reflection patterns of the sun (Danks & Good, 2016). Concave facade geometries with reflective materials can focus the reflection of the sunlight on one point and the reflection of the focused sunlight can seriously damage human eyesight or raise the ambient temperature above an acceptable level. Convex or jagged building facades do not focus or intensify, but they can make scattered sunlight reflections into larger areas so that neighbors can be influenced by reflected sunlight over a longer period. These concentrated or diffuse reflections of sunlight can pose a serious threat to motorists, as even a brief distraction can have serious consequences (M. Schiler & Valmont, 2005).

The building form is considered to be one of the most important decisions architects make during the design process. The form is determined by various factors such as the orientation of the site, the optimization of the surface, the structural requirements, laws and regulations, the possibilities of natural lighting and natural ventilation, etc. (Brzezicki, 2012). The form of the building is the most important factor in adding value to the environment. In addition to aesthetic aspects, sustainability aspects also become important points in the design of buildings due to their high energy consumption. During the design process, architects must take into account not only energy efficiency and user comfort but also the environmental impact of these important buildings and adapt the dimensions and skin form of the building according to these factors.

The building envelope is the main factor influencing the level of comfort of residents by providing visibility, natural lighting, natural ventilation, thermal insulation, soundproofing, etc. When it comes to the design of the building envelope, the increase in high-glazed facades is becoming the standard in modern architecture. Compared to insulated walls, they cause much more problems such as excessive heat build-up and uncontrolled natural light. Various strategies are being developed to address these problems. Internal shading devices such as blinds, curtains, or shutters, and external shading devices such as slats are used most frequently. However, shading devices are not always preferred for structural reasons (Rezaei et al., 2017).

2.1.6. Glare Nuisance to drivers and pedestrians

Suk, Schiler & Kensek (2017) state that glare is a cause for concern for drivers and pedestrians as it can restrict their field of vision and cause road accidents. Several accidents were reported, and drivers blown up by reflective lights experienced temporary visual impairment that resulted in the loss of life and property. Even if the source of glare does not directly affect the driver's view in some situations, behavior adjustments can be made to avoid glare. These adjustments can result in a decrease in the performance of the object lock, which is critical during the operation of a vehicle(Theeuwes et al., 2002). According to a study by the British Automobile Association, almost 3,000 accidents occur every year, and one in three people are affected by sun glare when driving through a zone with tall buildings. Especially at sunset or sunrise, when the sun's rays hit the earth at lower angles, direct sunlight and/or reflections from the environment can be critical.

2.1.7. The nuisance of glare to neighbor buildings

The reflectivity of the building facade can cause serious problems when it reaches an occupied space. The reflectivity of the sun can cause the temperature to rise in the area, which can cause discomfort and even property damage. The users of neighboring buildings may need to close their blinds or shades to minimize the inconvenience, although this action will limit their ability to get natural light or view during the day. It is also mentioned that in some cases of a significant temperature rise, residents are forced to keep their air conditioning on to avoid this problem from consuming much more energy(Naai Jung Shih & Huang, 2001) (N. J. Shih & Huang, 2001). The additional thermal stress caused by the reflection of the sun from neighboring buildings can change the indoor climate and the comfort of the residents by increasing the temperature and humidity.



Figure 2.4: The glare of Deutsche Bank and its reflection on its neighbor building. (Danks et al., 2016b)

2.1.8. Methods of outdoor glare estimation

There are several glare analysis methods available in the indoor environment of the building. Whereas in the outdoor environment or the form of glare that comes from the facade of the building is not an easy task. According to (Pierson et al., 2018) many factors affect visual discomfort, the computation or calculation of outdoor glare is not constant due to high variability between the location of the observer, elevation of the sun, angle of reflection, and type material that is used for building skin.

The high dynamic range imaging (HDRI) method is photography that attempts to represent the full dynamic range of a scene, from direct sunlight to deep shadow. It is a method to digitally capture and edit all light in a scene. It is used to analyze an HDR photo or simulation for potential glare, by generating series a of calibrated HDR images using a digital camera, Photosphere program, and luminance meter(Suk et al., 2017b).

The rendering approach used to analyze sun reflection is based on rendering. The most commonly used software is Radiance, either on its own or as part of a package like DIVA-for-Rhino or Open Studio. While it is very effective in estimating light reflectivity using indoor glare metrics, it has several disadvantages in calculating outdoor reflectivity. These disadvantages could be listed as; a

steep learning curve when using the software, requesting detailed data for physical material properties, and relatively slow due to the complex calculations(Suk et al., 2013).

The latest tools that have been used to determine solar reflectance are CFD packages like Star-CCM or Fluent. While it is a very advanced tool, there are drawbacks to this method as well. These software packages can include solar radiation and reflection from materials to predict the temperature of surfaces. However, the surface temperature depends on various and unpredictable factors such as local wind speeds and the ambient temperature of the area. These transient factors make it impossible to deliver an accurate result and lead designers down the wrong path early in the design phase. In addition, CFD tools, especially with complex building shapes, require an enormous amount of computing and cost (Danks & Good, 2016).

The geometric approach is the simplest and most labor-intensive technique that has been used. It is essentially based on the geometric relationship between the sun, the reflective surface, and the viewer. This approach is a trial-error system that assesses the problematic areas point by point by creating diagrams.

2.1.9. The geometric approach of glare assessment for drivers

Building solar reflections can cause veiling glare, which reduces visibility and increases the risk of traffic accidents. A veiling glare assessment usually consists of two steps. Firstly, identifying the number of geometrically possible reflections, and then quantifying whether these reflections are intense enough to cause glare. (Gil, 2016)

According to (Gil, 2016) Early approaches to assessing glare took a purely geometrical approach, aimed at simplifying the identification of solar reflections in 1926, Holladay developed a general formula to estimate the veiling glare based on several factors, equation

$$L_v = K * \frac{E}{\theta^n} \leq \text{threshold} \dots \dots \dots (1)$$

Where L_v (cd/m²) is the equivalent veiling luminance E (lux) is the direct illuminance reaching the observer's eye from the glare source; θ (degrees) is the glare angle between the observer's line of sight to the source of glare; K is a factor for observer's sensitivity; n is a factor related to the eye's focal sensitivity; The intensity ratio between the glare source and the background determines the threshold. If the value for equivalent veiling luminance exceeds the threshold, glare is considered possible. (Gil, 2016)

(Gil, 2016) states that, the sun is reflected towards any observer, and the equivalent veiling luminance in the eye of the observer is calculated and evaluated against the maximum allowed level of 500 Cd/m² according to Hassall. the driver's adaptation state can be defined as the amount of background light the retina receives under static conditions(Gil, 2016)

Table 2.1: Typical driver's adaptation state for different background lighting conditions

Background Lighting Condition	Driver's Adaptation State (cd/m ²)	Ambient Horizontal Illumination (lux)
Road at night	1-5	100
Late twilight/ early dawn	50	500
Early twilight / late dawn	250-500	5000
Overcast daytime sky	1000	10,000
Clear winter day	500-1500	30,000
Bright summer day	5000-6000	85,000 +

For the user's sensitivity (K factor), a value of 10 is commonly accepted, the sensitivity factor (n) represents how rapidly L_v responds to reductions in the glare angle. (Luckiesh & Holladay, 1939) A value of 2 is adequate for the most relevant glare angles, from 3° to 30°. For a smaller angle of reflected glare, a value of 3 is more adequate; beyond about 30° a value of 1 is used. (Gil, 2016) Where E (lux) solar illuminance at that elevation angle.

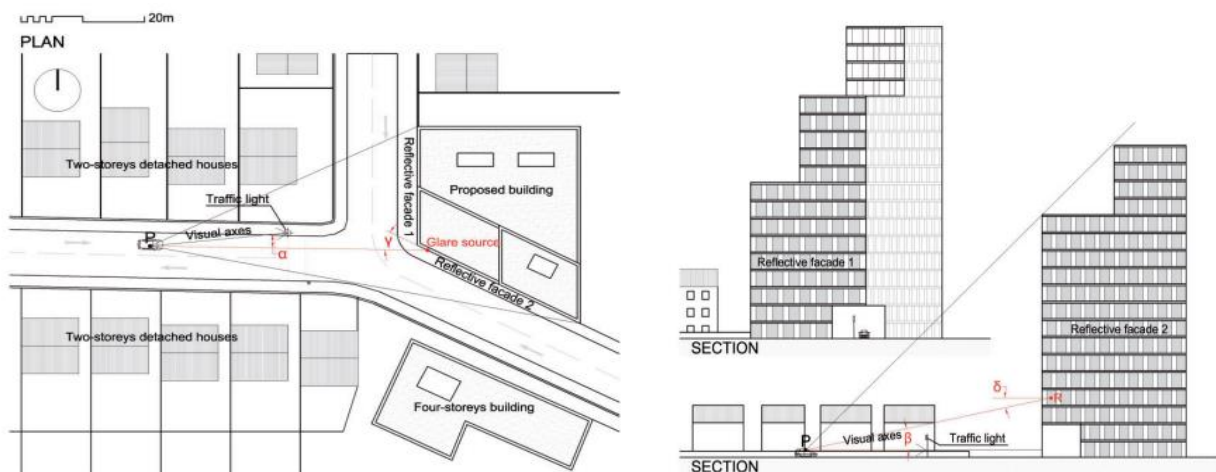


Figure 2.5: horizontal and vertical angles from the observer and the reflected glare source

Glare angle (θ): This is the angle between the glare source and the visual axes. It is a bit laborious to calculate and it requires precision to avoid meaningful errors in the value of θ , Horizontal angle α , and vertical angle β must be carefully measured.

$$\theta = \arctan (\sqrt{\tan^2\beta + \sin^2\alpha}/\cos \alpha) \dots \dots \dots (3)$$

2.1.10. Steps of assessment of undesirable solar reflection

The assessment of undesirable solar reflections is based on Hassall's methodology. This includes several steps, which are the dimensions, orientation, and degrees of reflective particles on every façade determined by an examination of the architect's drawings, the site and surroundings, and anticipated glazing Materials. Several observer locations are chosen to represent where the reflectivity of the façade can be observed. The times at which the sun is reflected off the facade, as well as the directions in which it is reflected, are determined. Finally, the equivalent veiling luminance in the observer's eye is calculated and compared to Hassall's maximum allowable level of 500 Cd/m².

2.1.11. Glare and Human Perception

(Kent et al., 2015) states that there is individual variability in the perceived level of visual discomfort. The glare was more frequently reported by older occupants, while detected a higher tolerance to discomfort glare in Japanese than in European subjects. Although glare is a subjective term, it could be defined as the presence of highly illuminated areas within the visual field of observers that affects visual performance and cause nuisance (Gelan, 2012).

Glare can sometimes hurt our vision. Light scatters inside the eye, and people can't see sharp images. With disabling glare, the loss of contrast is often worse in dim, not bright. (Vos, 2003)

2.1.12. Glare Sensitivity

Glare Sensitivity is a debilitating loss of visual acuity in bright lighting, such as when standing near a bright light source or when outside in direct sunlight. Glare-sensitive people will be unable to see the distinct contours of brightly lit objects, and their surroundings may merge into a "wall" of bright white. Glare sensitivity can be a symptom of certain eye conditions or a temporary side effect in our eyes. (van den Berg et al., 2009)

Age, glare time, glare duration, and glare avoidance all influence glare sensitivity. Age has a significant impact on avoidance and sensitivity in males, and age has a significant impact on sensitivity in females. The duration of glare has a significant impact on sensitivity. (Ishak et al., 2019) (van den Berg et al., 2009) States that, when the age increases the glare sensitivity also increases especially above the age of 40. On the other hand Independently of retinal illuminance, older people have difficulty with contrast vision due to neural changes in the retina and reduced binocular summation.

There are strong reasons to suspect that glare sensation varies with the time of day. Glare sensitivity affects by time which means glare has occurred at the lower sun angle. Naturally, glare occurs in the morning and the late afternoon. (Kent et al., 2015)

The ability of the retina of the eye to adjust to different levels of light is known as adaptation. Natural night vision, also known as scotopic vision, is the ability to see in low-light situations. Rod cells are solely responsible for night vision in humans because cone cells can only function at higher illumination levels. Eye adaptation has a significant impact on glare sensitivity. (Osterhaus, 2005)

2.1.13. Glare Mitigation Techniques

As mentioned in the previous part, there are tools for detecting sun reflections at the design stage. However, in some cases, these methods may be inadequate and the effects of sun reflection may go unnoticed until construction is complete. In this situation, it is not possible to change the form or orientation of the building. Therefore, some mitigation approaches should be pursued. Many mitigation techniques can be divided into two categories; Alter reflective surfaces and block sun reflections. (Danks et al., 2016a)

The reflective surface modification varies depending on the facade material used. If the problematic surface area is large and consists of glass systems, then different types of coatings in the form of films or sprays can be used. If the surface is small and made up of metal plates, roughening the surfaces with abrasive techniques or completely covering the surfaces with fabric or paint may be a solution. Roughening or covering the surface could only be used on opaque building materials as it is used on the outermost surface of the facade and completely changes the view of the residents(Danks et al., 2016a).

Blocking the reflection path could be simpler and cheaper than modifying the problematic surfaces. Another advantage of this method is that this can be done on the facade itself or along the reflection

path before reaching the surface. The shading devices can be of many shapes and sizes to block the sun's rays before they strike the surface or shortly after they are reflected. When implementing shading devices, additional structural loads, facade wind loads, ice and snow formation and aeroacoustics effects should be taken into account to avoid further problems.

According to (Danks et al., 2016a) it is preferred to block sun rays as close to the facade as possible, in some cases, it is preferable to use obstacles in the pedestrian area such as canopies, umbrellas, vegetation, or even billboards. However, this approach also has its difficulties. Due to the year-round movements of the center of gravity, it could become impossible to cover all problem areas and there could be considerable heat gains in the obstacle elements, which could even pose a danger to people and vegetation in the area.

2.2. Empirical Literature Review

2.2.1. Reflected glare issues in Sydney

In 1992, Sydney City Council proposed a criterion of 500 candelas per square meter for "maximum reflected solar glare" (veiling luminance) on vehicle drivers for glare impact on occupants of neighboring buildings. Later, Sydney City Council limited the normal reflectivity of a building's exterior surface to 20%. Most local governments in the Sydney metropolitan area have followed. (Rofail et al., 2004)

2.2.2. Reflected glare issues in Singapore

(Rofail et al., 2004) states that Singapore and Rotterdam have taken a similar approach. Singapore's current reflectivity limit of 10% is about to be increased to 15%. This is a positive and practical move, but it may not be sufficient in some situations. On the other hand, this restriction on the reflectivity of a building's exterior surface may be overly restrictive, particularly when the orientation of the building lends itself to measures that can offset the additional glare, such as increasing the depths of the mullions. (Ishak et al., 2019)

2.2.3. Reflected glare issues in Hong Kong

Due to the residents raised the question to the government of Hong Kong, the residents of the central business district and some motorists have complained, that the glass curtain walls of the International Finance Centre reflect sunlight from a low angle directly in front of them, making them unable to keep their eyes open and compromising road safety. Some Yau Tsim Mong District residents have also complained that the International finance Centre's glass curtain walls reflect sunlight into their homes, disrupting their daily lives. Regarding light pollution caused by sunlight reflected by glass curtain walls of buildings, the Government of Hong Kong set guidelines in September 2014, needing that the glazed portion of the building envelope (such as walls and windows) of residential buildings and residents' recreational facilities have an external reflectance (i.e. the percentage of daylight reflected from a glass surface) of no more than 20% as one of the requirements for granting gross floor area concessions for residential buildings. In April 2015 the guideline also extends the application of a similar guideline to commercial buildings. (Rofail et al., 2004)

2.3.The gap in Literature Review

Researchers tried to assess the theoretical evidence in the area of the outdoor building envelope glare issues. However, there is no empirical evidence in the study of outdoor glare issues in the context of Ethiopia as well as in Africa. So, there is a limitation of reference documents for outdoor glare issues on the building facades in the Ethiopian context.

CHAPTER THREE

3. MATERIAL AND METHOD

3.1. Introduction

This chapter deals with the materials and methods that are used for collecting and analyzing data. The methodology is presented sequentially to get a legible and accurate scientific data handling technique. The methods are based on the literature review from previous studies to gain knowledge and information regarding the scope of the research. It mainly describes how the study was conducted, the applied methods and techniques in data collection, and data analysis, and the reasons why they were used according to the objective of the study.

3.1.1. Description of the study area

Addis Ababa, the national capital of Ethiopia, located 8.9806° N; 38.7578° E covers an area of 527 square kilometers, 2,355 m above sea level. Addis Ababa has a population of about 4 million inhabitants. The city was founded in 1887.

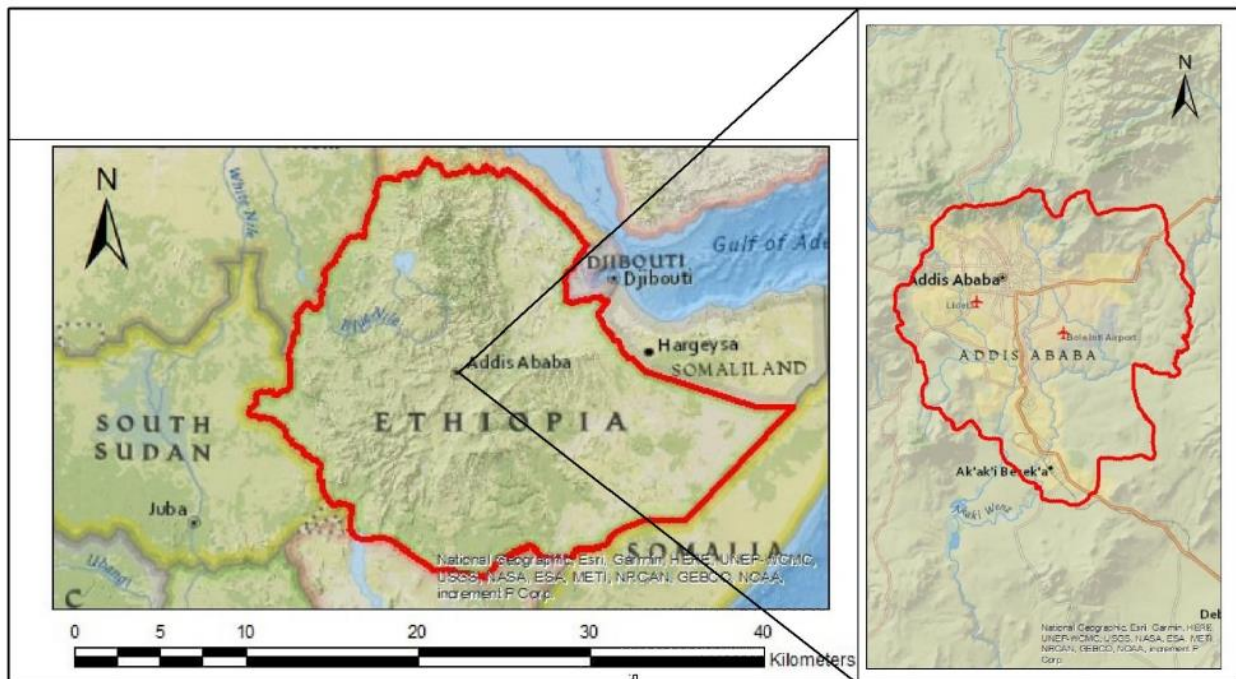


Figure 3.1: Location map of the study Addis Ababa

3.2. Research design

The design of the study is quantitative research, and the method used when collecting, processing, and analyzing the gathered information is quantitative research method.

For the first and second objectives, the research approach is deductive because the assessments of measured reflected glare illuminance for both drivers and nearby occupants are based on a set of theories and standards. For the third objective, the research approach is inductive, because the assessment of the third objective is based on the influence of reflected glare on the perception of pedestrians along sidewalks.

3.3.Types and Sources of the Data

To accomplish the purpose of this research, data have been collected from both primary and secondary sources. As far as secondary data are concerned books, journal articles, and official documents were used as a source. The basic data of this research is the illuminance level of the building's sunlight reflection and the illuminance of incident rays in the outdoor environment such as on roads and nearby residents' areas.

The passer's perception data is collected through the questionnaire. The questionnaire is structured by age, glare time, and glare duration, and glare adaptation act as independent variables, glare sensitivity is the dependent variable the data is collected and analyzed collectively. (Appendix, F)

3.4. Sample size and Sampling techniques

The sample buildings were identified through purposive sampling. It is one type of non-probability sampling method in which the researcher relies on judgments when choosing the samples.

3.4.1. Selection Criteria of study buildings

The study buildings were selected under these criteria: orientation, height, and the material of the building.

Orientation of the buildings

The orientation of a building is a significant architectural concern, particularly in terms of environmental influences (i.e. temperature, humidity, air speed, and daylight illumination) (Woods, 2014). The orientation of the building envelope determines the quantity of solar radiation that it receives and also reflects on the environment. Most of the time glare occurs at the lower angle of sun

elevation so the lower angles of solar elevation happen in the early morning and the late afternoon. So the sun naturally set in the west direction. The lower angle of the sun elevation is started from in the southwest direction. (Pohl, 2011) Therefore, the researcher chooses the orientation of the building in the west and southwest directions.

Height of buildings: High-rise buildings with fully glazed façade systems, contributes to glare issue through solar reflectivity properties of their skin. (Ishak et al., 2019) The high-rise building is not easily shaded by built environments of the surrounding environment. So the researcher set criteria to select buildings that have greater than ten-story.

Materials of building skin (Building Envelop): Glass is more and more used in building envelopes. To achieve the goal of saving energy and reducing cooling load, facade designers prefer high reflective glass. (Ishak et al., 2019) the glass is a more reflective building envelop material so the researcher set criteria for the sample buildings to have glazed building envelop.

3.4.2. Case buildings selection

The sample buildings were selected in central business areas of Addis Ababa namely piazza, Bole, Mexico, and Megenaga were the focus of the study. Those areas were selected due to the current government interest for renewal, there are numerous commercial and office buildings that have fully and partially glazed façades constructed and under construction.

With purposive sampling, the buildings were selected based on the preliminary measurement that contains the selection criteria. The checklist was prepared to select sample buildings (Appendix A). For the selected business district areas, based on the orientation of the streets that have oriented in west and south west were chosen. Therefore, In Piazza Churchill Avenue (west), in Mexico Ras Abebe Aregay street (southwest), In Bole area Africa avenue (southwest), from Megenaga Maryam road (southwest) 42 buildings were selected. From 42 buildings, the height of the buildings that is above 10 story was selected, which is 11. From 11 buildings, the material of the buildings that is fully glazed, and partially glazed buildings skin was selected, which is 5.

Therefore, based on the above criteria five buildings were selected. These are respectively Awash bank and insurance Sc. at kirkos sub-city on Ras Abebe Aregay Street, Churchill hotel is located at Arada sub city on Churchill Avenue, National oil Ethiopia located at Bole sub city Africa Avenue, Eshetu Mamo commercial center located at Arada sub city on Churchill Avenue, and Dirar mall is located in Yeka sub city Mariam road in the city of Addis Ababa.

3.4.3. Awash Bank and Insurance SC head office

Awash bank and insurance SC building are located in the financial district of Addis Ababa. The building mass is convexly formed the skin of the building is built from the glass curtain wall. Awash Insurance Company is a 16th-floor building designed for bank and insurance administration offices. It consists of two transparent semicircular wings that are connected to pedestrian bridges on different floors.

The southwest facade of Awash bank and the insurance company has a convex shape covered with a highly reflective glass curtain wall that makes scattered rays. And the rays are reflected daylight in the environment. The reflected sunlight makes glares across the street as well as the nearby buildings as seen in figure 3.2. On sunny days the large glazed facade causes a glare on the outside environment.



Figure 3.2: Awash bank and insurance SC building

3.4.4. Churchill Hotel

Churchill hotel is located at Churchill Avenue, Piazza in Addis Ababa. The building facade is the planner and curved from the skin of the building is a glass curtain wall and aluminum cladding. Churchill hotel is a 10th-floor building designed for hotel purposes.

The west facade of Churchill hotel has both planner and a convex shape facade. The building reflects sunlight towards the sun's direction, which makes glare pollution. The reflected sunlight ray makes glares across the street and plantation the nearby buildings as seen in figure 3.3.



Figure 3.3: Churchill Hotel

3.4.5. National oil Ethiopia (NOC) headquarters

National oil Ethiopia (NOC) is located in bole at Africa Avenue, Addis Ababa. The skin of the building is a glass curtain wall. National oil Ethiopia (NOC) is a 16th-floor building its height is 62.58m used for the head office of NOC.

The southwest facade of National oil Ethiopia (NOC) has an oval shape façade. The building reflects daylight towards the sun's direction, which makes scattered rays that reflect on the nearby buildings and the surrounding environment. The reflected sunlight ray makes glare across the street and the nearby buildings as seen in figure 3.4.



Figure 3.4: National oil Ethiopia (NOC)

3.4.6. Eshetu mamo Commercial center

Eshetu mamo commercial center is located in the business district of Piazza at Churchill Avenue. The building facade is flat and inclined forming the skin of the building is a glass curtain wall. Eshetu mamo commercial center is a 10th-floor building designed for commercial purposes.

The west facade of Eshetu mamo commercial center has both planner and angular facade. The building reflects daylight towards the sun's direction, which makes glare pollution. The reflected sunlight ray makes glare across the street and plantation as seen in figure 3.5.



Figure 3.5: Eshetu Mamo commercial center

3.4.7. Dirar Mall

Dirar Mall is located in Sealite Mihret square. The building facade is planner and curved form the skin of the building is a glass curtain wall. Dirar Mall is a 10th-floor building designed for commercial purposes.

The southwest facade of Dirar Mall has both planner and curved facade. The building reflects sunlight towards the sun's direction, which makes glares at the road and the nearby buildings as seen in figure 3.6 below.



Figure 3.6: Dirar Mall

3.5. Sample Size Determination

Besides, in the selection of the buildings pedestrians were considered as a sampling unit to assess the passers-by's visual satisfaction perception due to the reflected façade. So, to estimate the pedestrian volume a short-duration manual counting method is used. A manual tally counter phone method is used to perform a mid-block manual count of a pedestrian. A long of sample buildings within 100 meters radius. The short-duration counting is made for 7 days. Counting is done for each day from 4:00 pm to 5:00 pm (see appendix B (B1,B2,B3,B4,B5)). The Sum of the daily average count is the total population number and using Yamane, 1967 formula the sample is generated.

For known population size, the Yamane formula for determining the sample size is given by:

$$\text{Sample size (n)} = \frac{N}{1+N(e^2)} \dots \dots \dots \text{eq3}$$

Where, n= corrected sample size, N = population size, and e = margin of error (MoE), 95% confidence level $e \pm 5\%$, $e = 0.05$.

The population is 3344. At 5% MoE, the sample size would be: $3344 / (1 + 3344 (0.05^2)) = 3344 / 9.36 = 357.21 \sim 357$

The simple random sampling method has been used for the survey. Because each sample has an equal chance of being selected. The population surveyed was divided into selected five different locations based on the density of the population.

Table 3.1 Population size of each area

No	Buildings	population size	Total percent	Distributed
1	Awash bank and insurance Sc.	763	22.82	81
2	Churchill Hotel	721	21.56	77
3	National oil Ethiopia	641	19.17	68
4	Eshetu Mamo commercial center	636	19.02	68
5	Dirar mall	583	17.43	62
total		3344	100.00	357

3.6. Data Collection Instruments and methods

Illuminance is the measure of the amount of light received on a surface. It is typically expressed in lux (lm/m^2). It is the measure of light currently used by most performance indicators to determine daylight availability. Illuminance levels can be measured with a lux meter. The accuracy of the lux meter used for the research is $23 \pm 5^\circ\text{C}$: $\pm 5\%$ of reading $\pm 10 + 2d$ range 0-2,000 /2,000-19, 99/20,000-50,000.

The passer's perception data is conducted through the questionnaire. The questionnaire is structured by age, glare time, and glare duration, and glare adaptation act as independent variables, glare sensitivity is the dependent variable the data is collected and analyzed collectively. (Appendix, D)

3.6.1. Reflected light measurement

A Lux meter was used to measure the illuminance level reflected sunlight in selected buildings at different times of the day the data are collected from 05/03/2022 up to 20/03/2022. The measurement was done at different times of day at 4:00 pm, 4:30 pm, and 5:00 pm because glare is occurred at the lower sun angle and to understand the impact of the solar reflection through the environment.



Figure 3.7: Digital lux meter

3.6.1.1.Data collection method for the drivers' visual comfort

For Awash bank and insurance SC building, the measurement was taken on 05/03/2022 at different times as well as at different locations of the drivers' positions on the road. At 4:00 pm the location of measurement was at point P1, at 4:30 pm the location of measurement was at point P2, and at 5:00 pm the location of measurement was at point P3. The locations were set according to the reflected ray position, which means when the time changes and the position of the reflected ray also changes. From P1, P2, and P3, the measurements of reflected glare illuminance (E), horizontal distances between drivers standing point to glare sources (HD), and the horizontal angle between the drivers' standpoint to the glare source (α) was measured. And for vertical distance (VD), the heights of the glare source were measured each time.

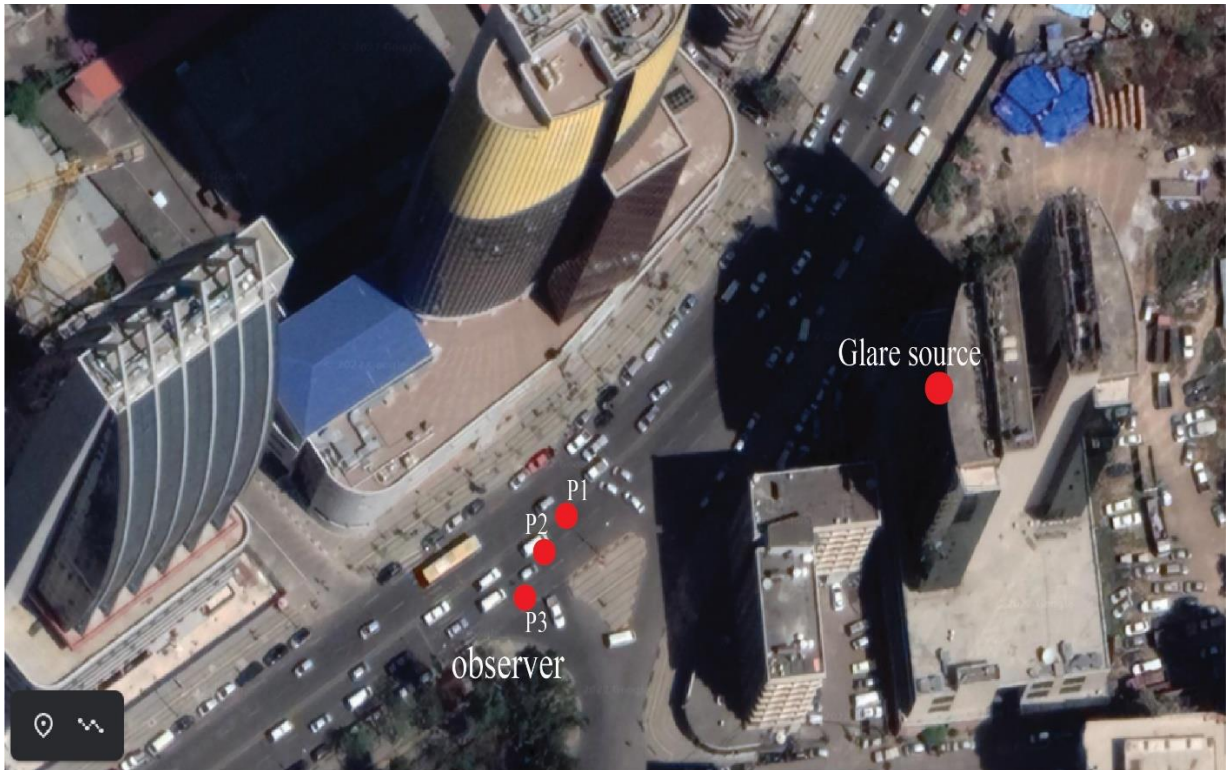


Figure 3.8: Data collection at the road near to Awash Bank building

For the Churchill Hotel building, the measurement was taken on 08/03/2022 at different times as well as at different locations of the drivers' positions on the road. At 4:00 pm the location of measurement was at point P1, at 4:30 pm the location of measurement was at point P2, and at 5:00 pm the location of measurement was at point P3. From P1, P2, and P3, the measurements of reflected glare illuminance (E), horizontal distances between drivers standing point to glare sources (HD), and the horizontal angle between the drivers' standpoint to the glare source (α) was measured. And for vertical distance (VD), the heights of the glare source were measured each time.



Figure 3.9: Data collection at the road near to Churchill Hotel

For the NOC building, the measurement was taken on 11/03/2022 at different times as well as at different locations of the drivers' positions on the road. At 4:00 pm the location of measurement was at point P1, at 4:30 pm the location of measurement was at point P2, and at 5:00 pm the location of measurement was at point P3. From P1, P2, and P3, the measurements of reflected glare illuminance (E), horizontal distances between drivers standing point to glare sources (HD), and the horizontal angle between the drivers' standpoint to the glare source (α) was measured. And for vertical distance (VD), the heights of the glare source were measured each time.



Figure 3.10: Data collection at the road near to NOC building

For Awash bank and insurance SC building, the measurement was taken on 13/03/2022 at different times as well as at different locations of the drivers' positions on the road. At 4:00 pm the location of measurement was at point P1, at 4:30 pm the location of measurement was at point P2, and at 4:00 pm the location of measurement was at point P3. From P1, P2, and P3, the measurements of reflected glare illuminance (E), horizontal distances between drivers standing point to glare sources (HD), and the horizontal angle between the drivers' standpoint to the glare source (α) was measured. And for vertical distance (VD), the heights of the glare source were measured each time.

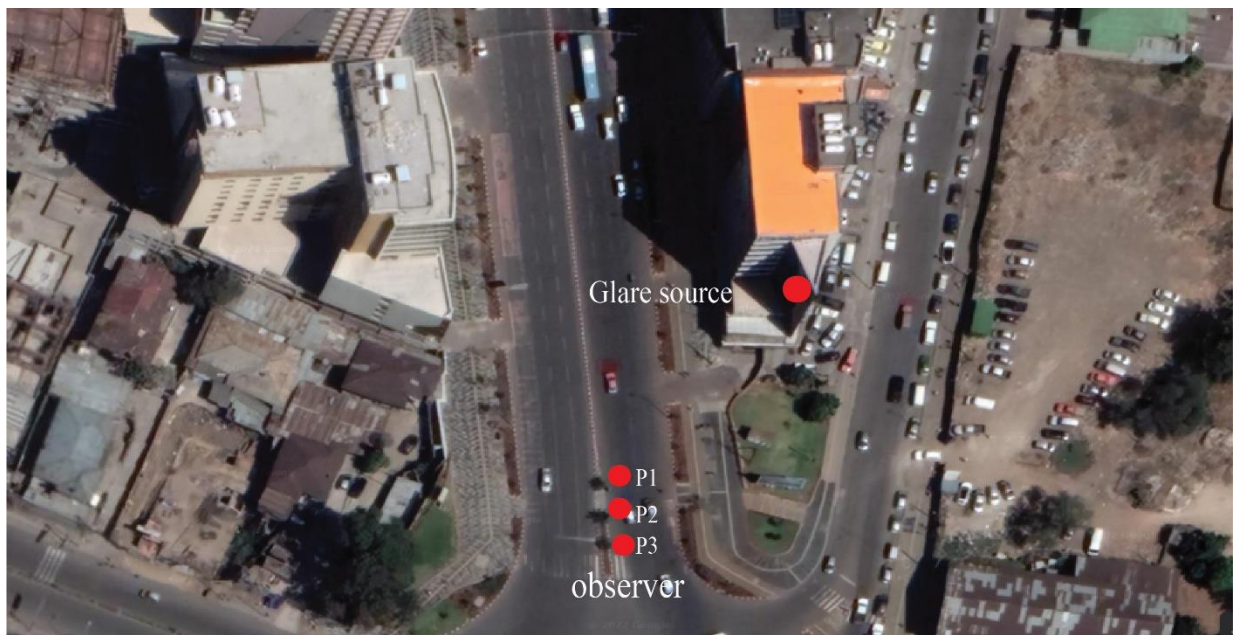


Figure 3.11: Data collection at the road near to Eshetu Mamo building

For Dirar mall the measurement was taken, on the day 20 /03/2022 at different times and different locations of the drivers' positions on the road. At 4:00 pm the location of measurement was at point P1, at 4:30 pm the location of measurement was at point P2, and at 5:00 pm the location of measurement was at point P3. From P1, P2, and P3, the measurements of reflected glare illuminance (E), horizontal distances between drivers standing point to glare sources (HD), and the horizontal angle between the drivers' standpoint to the glare source (α) was measured. And for vertical distance (VD), the heights of the glare source were measured each time.



Figure 3.12: Data collection at the road near Dirar mall

3.6.1.2. Data collection method for the nearby residents

For the Awash bank and insurance SC building, the measurements were taken at the neighboring building frontage that affects by reflected glare. The measurement was taken on 06/03/2022 from 4:00 pm to 5:00 pm at 15-minute intervals. The measurement of the reflected ray was done at the frontage of the nearby building that is located in front of Awash building across the road within 30-meter length along the road, five times from 4:00 pm to 5:00 pm. And the measurement of the incident ray was done directly from the sun five times.



Figure 3.13: Data collection at neighboring Awash Bank building

For the Churchill Hotel building, the measurement was taken at the neighboring building frontage that affects by reflected glare. The measurement was taken on 09/03/2022 from 4:00 pm to 5:00 pm at 15-minute intervals. The measurement of the reflected ray was done at the frontage of the nearby building that is located in front of Churchill Hotel building across the road within 30-meter length along the road five times from 4:00 pm to 5:00 pm. And the measurement of the incident ray was done directly from the sun five times.



Figure 3.14: Data collection at neighboring Churchill Hotel

For the NOC building, the measurement was taken at the neighboring building frontage that affects by reflected glare. The measurement was taken on 12/03/2022 from 4:00 pm to 5:00 pm at 15-minute intervals. The measurement of the reflected ray was done at the frontage of the nearby building that is located in front of NOC across the road within 30-meter length along the road five times from 4:00 pm to 5:00 pm. And the measurement of the incident ray was done directly from the sun five times.

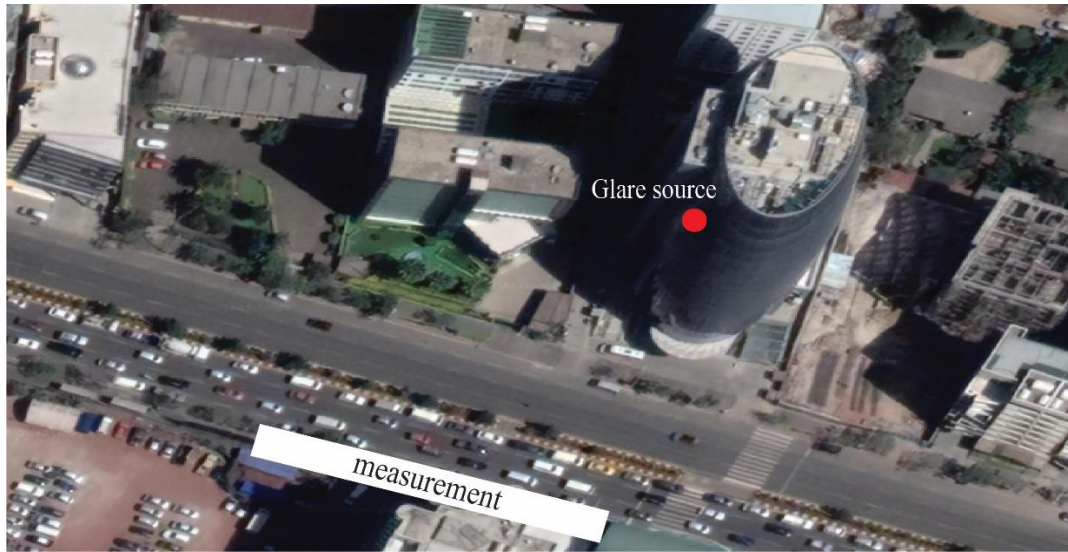


Figure 3.15: Data collection at neighboring NOC building

For the Eshetu mammo building, the measurement was taken at the neighboring building frontage that affects by reflected glare. The measurement was taken on 14/03/2022 from 4:00 pm to 5:00 pm at 15-minute intervals. The measurement of the reflected ray was done at the frontage of the nearby building that is located in front of Eshetu mammo commercial center across the road within 30-meter length along the road five times from 4:00 pm to 5:00 pm. And the measurement of the incident ray was done directly from the sun five times.

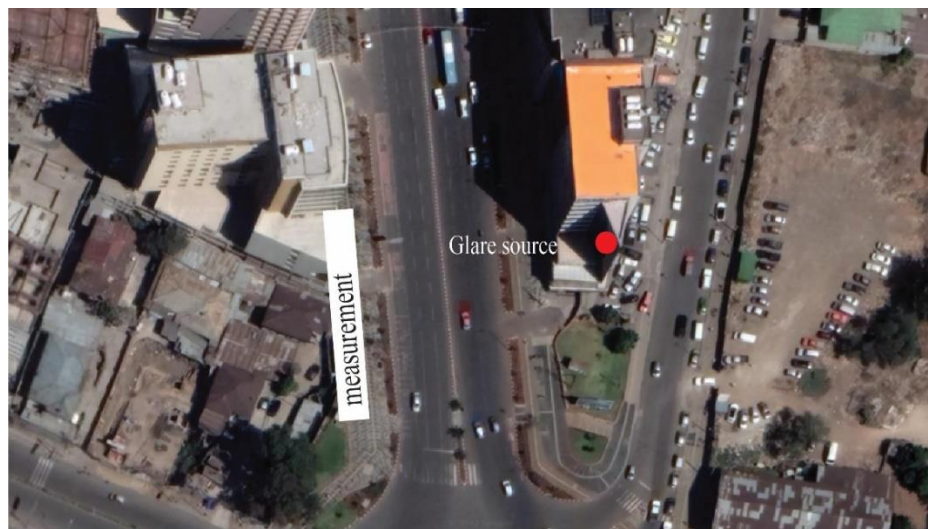


Figure 3.16: Data collection at the neighboring Eshetu Mamo building

For the Dirar mall building, the measurement was taken at the neighboring building frontage that affects by reflected glare. The measurement was taken on 16/03/2022 from 4:00 pm to 5:00 pm at 15-minute intervals. The measurement of the reflected ray was done at the frontage of the building that is located in front of Dirar mall across the road, with a 30-meter length along the road five times from 4:00 pm to 5:00 pm. And the measurement of the incident ray was done directly from the sun five times.



Figure 3.17: Data collection at neighboring Dirar mall

3.6.2. Data collection methods for human perception

The questionnaires were used to assess the visual comfort regarding solar glare of the passers near the selected five buildings. These are respectively awash bank and insurance Sc. at Ras Abebe Aregay Street, Churchill hotel at Churchill Avenue, National oil Ethiopia at Africa Avenue, Eshetu Mamo commercial center at Churchill Avenue, and Dirar mall at Mariam road in the city of Addis Ababa. The data collection was done on 18/03/2022 from 4:00 pm to 5:00 pm. The questionnaires were distributed based on the population size of the pedestrians in selected areas.

(Kent et al., 2015) states that there is individual variability in the perceived level of visual discomfort. The questionnaire is structured by four independent variables which are age, glare time, glare

duration, and glare adaptation. The dependent variable is glare sensitivity which is used to quantify the perceived glare level of the sample buildings (Ishak et al., 2019)

3.7.Method of Data Analysis

3.7.1. Method of analysis for drivers' visual comfort

The measured illuminance level of reflected sunlight, regarding the observer's horizontal and vertical distances and angles from the glare source at different times, was recorded carefully. The geometrical analysis method done by using Holladay's general formula veiling glare intensity (L_v), is calculated from, $L_v = K * \frac{E}{\theta^n} \leq \text{threshold}$, E is solar illuminance which is directly measured from the glare source at that elevation angle, Observer's sensitivity (K); the sensitivity factor (k) which takes into account the age of the driver for analysis the researcher assume $k = 10$ for middle age person, The eye's focal sensitivity(n); The sensitivity factor (n) represents how rapidly equivalent veiling luminance responds to reductions in the glare angle it is depends on the angle vertical angle (β). A value of 2 is adequate for the most relevant glare angles, from 3° to 30° . For a smaller angle below 3° of reflected glare, a value of 3 is more adequate; beyond about 30° a value of 1 is used. (Gil, 2016) The glare angle (θ) is the angle between the glare source and the visual axes, which is calculated as $\theta = \arctan(\sqrt{\tan^2\beta + \sin^2\alpha}/\cos\alpha)$ Horizontal angle (α) and vertical angle (β) angle are measured from the observers' visual axes. (Gil, 2016) The vertical angle (β) is calculated; $\beta = \arctan(VD/HD)$ VD is the vertical distance between the glare source to the driver's line of sight, and HD is the horizontal distance between the driver's standing point to the glare source (α) is the horizontal angle between the drivers' standpoint to the glare source which is measured on the field.

Finally, veiling glare intensity (L_v) is calculated. The calculated value (L_v) is compared to the recommended veiling glare threshold (500cd/m^2).

3.7.2. Method of data analysis for the neighboring building's residents

The analysis is based on the Sydney City Council of buildings standard which is, the maximum level of solar reflectivity that bounces off from the building's exterior envelope must not exceed 20% of the incident ray. So, the measured luminance levels of the incident ray were compared to the luminance level of reflected ray.

3.7.3. Perception Data Analysis

After the data collection, the variables are coded on SPSS and a normality and homogeneity test is made to check the consistency of the data. To understand the relation between the variables, one-way ANOVA is used for data analysis. One-way ANOVA is done to understand the relationships between each independent variable, age groups with sensitivity, time interval with glare sensitivity, glare duration with sensitivity, and glare adaptation with sensitivity.

3.7.4. Ethical Consideration

Ethical approval is obtained from the Department of Architecture. Both oral and written informed consent is obtained from each study participant after thoroughly explaining the objectives and benefits of the study. To ensure confidentiality, any personal identifying information on participants is not collected. Data collected for this study is not used for another study without the approval of each participant.

Table 3.2: The summary of all material and methods based on the specific objectives

No	Specific objective	Data used	Collection method	Analysis
1	To assess the impact of reflective building facades on drivers' visual comfort	Illuminance level of reflected sunlight on the road.	Measuring reflected sunlight Using lux meter	Holladay's veiling glare formula then compare with the threshold
2.	To assess the impact of the reflective façade on the neighboring residents' visual comfort	Measuring the illuminance level reflected and incident ray at the neighboring building	Measuring the incident and reflected light	Using Sidney city standards
3.	To assess the impact of the reflective façade on the pedestrian's visual comfort	The negative effect will be identified	Questionnaire	SPSS, Excel

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. Drivers' visual comfort

4.1.1. Awash Bank and Insurance SC head office

The sensitivity factor (n) is calculated from the glare angle $\theta = 15.53, 14.82$, and 11.21 so all angles are within the range of from 3^0 to 30^0 there for value of 2 is adopted, For the user's glare sensitivity (K factor) a value of 10 is adopted for middle age person. (Gil, 2016),

L_v (cd/m^2) is the equivalent veiling luminance at different times of the day and is calculated (table 4.1) the maximum equivalent glare for awash bank and Insurance SC was obtained at 5:00 pm which is 413.19 cd/m^2 the illuminance of the glare source is as the veiling glare caused by the reflection is within the recommended limit (500 cd/m^2). Therefore it is unlikely to cause glare.

Table 4.1: Equivalent veiling luminance for Awash bank and Insurance SC building

Time	E	β	α	θ	k	n	$L_v = K * E / \theta^n$
4:00 pm	8710	14.20	6.50	15.53	10	2	360.96
4:30 pm	7950	13.16	7.00	14.82	10	2	361.95
5:00 pm	5190	7.95	8.00	11.21	10	2	413.19

4.1.2. Churchill Hotel

The measurement was done on three different points on 08/03/2022 at different times. The constants are the sensitivity factor (n) the glare angle $\theta = 20.89, 10.50$, and 8.91 so all angles are within the range of from 3^0 to 30^0 there for value of 2 is adopted, For the user's glare sensitivity (K factor) a value of 10 is adopted for middle age person. (Gil, 2016),

(table 4.2) shows, that L_v (cd/m^2) is the equivalent veiling luminance at different times of the day calculated the maximum equivalent glare for the Churchill Hotel building was obtained at 4:30 pm which is 225.05 cd/m^2 . The illuminance of the glare source is as the veiling glare caused by the reflection is within the recommended limit (500 cd/m^2). Therefore it is unlikely to cause glare.

Table 4.2: Equivalent veiling luminance for Churchill hotel building

Time	E	α	β	θ	k	n	$L_v = K * E / \theta^n$
4:00 pm	9380	16.00	14.24	20.89	10	2	214.98
4:30 pm	7240	15.00	10.50	17.94	10	2	225.05
5:00 pm	6230	14.50	8.91	16.70	10	2	223.31

4.1.3. NOC Building

The measurement was done on three different points on 11/03/2022 at different times. The constants are the sensitivity factor (n) the glare angle $\theta = 20.86, 16.79$, and 15.12 so all angles are within the range of 3^0 to 30^0 there for value of 2 is adopted, For the user's glare sensitivity (K factor) a value of 10 is adopted for middle age person. (Gil, 2016),

(table 4.3) shows, that L_v (cd/m²) is the equivalent veiling luminance at different times of the day calculated the maximum equivalent glare for the NOC building was obtained at 4:30 pm which is 240.77 cd/m². The illuminance of the glare source is as the veiling glare caused by the reflection is within the recommended limit (500 cd/m²). Therefore it is unlikely to cause glare.

Table 4.3: Equivalent veiling luminance for NOC building

Time	E	α	β	θ	k	n	$L_v = K * E / \theta^n$
4:00 pm	7630	17.20	12.80	20.86	10	2	175.38
4:30 pm	6790	14.00	9.82	16.79	10	2	240.77
5:00 pm	5170	13.50	7.32	15.12	10	2	226.28

4.1.4. Eshetu Mamo commercial center

The measurement was done on three different points on 13/03/2022 at different times. The constants are the sensitivity factor (n) the glare angle $\theta = 12.34, 8.14$, and 6.91 so all angles are within the range of from 3^0 to 30^0 there for value of 2 is adopted, For the user's glare sensitivity (K factor) a value of 10 is adopted for middle age person. (Gil, 2016),

(table 4.4) shows, L_v (cd/m²) is the equivalent veiling luminance at different times of the day calculated the maximum equivalent glare for Eshetu Mamo commercial center was obtained at 4:30 pm which is 323.25 cd/m². The illuminance of the glare source is as the veiling glare caused by the reflection is within the recommended limit (500 cd/m²). Therefore it is unlikely to cause glare.

Table 4.4: Equivalent veiling luminance for Eshetu Mamo commercial center

Time	E	α	β	θ	k	n	$L_v = K * E / \theta^n$
4:00 pm	9510	16.0	12.34	19.72	10	2	244.44
4:30 pm	8190	14.0	8.14	15.92	10	2	323.25
5:00 pm	7210	16.5	6.91	17.49	10	2	235.66

4.1.5. Dirar mall

The measurement was done on three different points on 20/03/2022 at different times. The constants are the sensitivity factor (n) the glare angle $\theta = 11.45, 10.08$, and 7.56 so all angles are within the range of from 3° to 30° there for value of 2 is adopted, For the user's glare sensitivity (K factor) a value of 10 is adopted for middle age person. (Gil, 2016),

(table 4.5) shows, that L_v (cd/m^2) is the equivalent veiling luminance at different times of the day calculated the maximum equivalent glare for Dirar mall was obtained at 5:30 pm which is 374.69 cd/m^2 . The illuminance of the glare source is as the veiling glare caused by the reflection is within the recommended limit (500 cd/m^2). Therefore it is unlikely to cause glare.

Table 4.5: Equivalent veiling luminance for Dirar mall

Time	E	α	β	θ	k	n	$L_v = K * E / \theta^n$
4:00 pm	8260	11.00	11.45	15.68	10	2	336.01
4:30 pm	8540	11.50	10.08	15.10	10	2	374.69
5:00 pm	6580	12.00	7.56	14.00	10	2	335.55

4.2.Nearby residents' comfort

The results incident ray varies at different times whereas the building façade constant reflection.

4.2.1. Awash Bank and Insurance building SC

Table 4.6, shows, that the average measured reflection at 4:00 pm is 46.55 %, 4:15 pm is 46.23 %, 4:30 pm is 45.77 %, 4:45 pm is 46.52 %, 5:00 pm is 45.09 %. The measured daily average reflected rays are greater than the maximum allowable threshold.

Table 4.6: Awash bank and insurance building measured light illuminance in lux (lm/m²).

Day	Time	Incident ray	Reflected ray from façade	Average % reflection
6/3/2022	4:00 PM	23200	10800	46.55
	4:15 PM	21200	9800	46.23
	4:30 PM	20100	9200	45.77
	4:45 PM	18700	8700	46.52
	5:00 PM	17300	7800	45.09
		19920	9260	46.49

4.2.1. Churchill Hotel

Table 4.7, shows, that the average measured reflection at 4:00 pm is 44.06 %, 4:15 pm is 44.51 %, 4:30 pm is 44.15 %, 4:45 pm is 44.32 %, 5:00 pm is 44.71 %. The measured daily average reflected rays are greater than the maximum allowable threshold.

Table 4.7: Churchill hotel measured light intensity in lux (lm/m²)

Day	time	Incident ray light	Reflected ray	20% of an incident ray light
9/3/2022	4:00 PM	21200	9340	44.06
	4:15 PM	19300	8590	44.51
	4:30 PM	16400	7240	44.15
	4:45 PM	14800	6560	44.32
	5:00 PM	12100	5410	44.71

4.2.2. NOC

Table 4.8, shows, that the average measured reflection at 4:00 pm is 41.01 %, 4:15 pm is 41.41 %, 4:30 pm is 41.56 %, 4:45 pm is 41.51 %, 5:00 pm is 41.87 %. The measured daily average reflected rays are greater than the maximum allowable threshold.

Table 4.8: National oil Ethiopia building (NOC) measured light intensity in lux (lm/m²).

Day	Time	Incident ray on façade	Reflected ray	Average % reflection
12/3/2022	4:00 PM	21700	8900	41.01
	4:15 PM	18400	7620	41.41
	4:30 PM	16700	6940	41.56
	4:45 PM	14600	6060	41.51
	5:00 PM	13900	5820	41.87
		17060	7068	41.47

4.2.3. Eshetu Mamo comercial center

Table 4.9, shows, that the average measured reflection at 4:00 pm is 47.97 %, 4:15 pm is 47.37 %, 4:30 pm is 47.53 %, 4:45 pm is 47.71 %, 5:00 pm is 47.63 %. The measured daily average reflected rays are greater than the maximum allowable threshold.

Table 4.9: Eshetu Mamo commercial center measured light intensity in lux (lm/m²).

Day	Time	Incident ray	Reflected ray	Reflection %
14/3/2022	4:00 PM	23100	11080	47.97
	4:15 PM	19800	9380	47.37
	4:30 PM	17800	8460	47.53
	4:45 PM	14400	6870	47.71
	5:00 PM	13100	6240	47.63
		17640	8406	47.64

4.2.4. Dirar Mall

Table 4.10, shows, that the average measured reflection at 4:00 pm is 31.16 %, 4:15 pm is 31.68 %, 4:30 pm is 31.98 %, 4:45 pm is 31.55 %, 5:00 pm is 31.45 %. The measured daily average reflected rays are greater than the maximum allowable threshold.

Table 4.10: Dirar Mall measured light intensity in lux (lm/m²).

Day	Time	Incident ray	Reflected ray from façade	Average % reflection
5/3/2022	4:00 pm	22400	6980	31.16
	4:15 pm	21400	6780	31.68
	4:30 pm	20200	6460	31.98
	4:45 pm	18700	5900	31.55
	5:00 pm	17300	5440	31.45
		20000	6312	31.56

4.3. Pedestrians' visual satisfaction due to the reflected façade

4.3.1. Glare duration

Table 4.11, shows the duration of the glare that pedestrians are experienced on the sidewalk. Based on the response of the respondent 31.6 % of the respondent experienced a 30-45 min duration of the glare, 27.9 % of the respondent experienced a 45-60 minute duration of the glare, 11.7% experienced below 15 minutes, 21.2 % are experienced 15-30 minute and 7.7 % of the respondent have experienced above the 60-minute duration of the glare.

Table 4.11: The duration of the glare

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Below 15	38	11.7	11.7	11.7
	15-30	69	21.2	21.2	32.8
	30-45	103	31.6	31.6	64.4
	45-60	91	27.9	27.9	92.3
	Above 60	25	7.7	7.7	100.0
	Total	326	100.0	100.0	

4.3.1.1. Glare time

Table 4.12 shows, Based on the response of the respondent 46 % of the respondent experienced 10 - 11 pm glare time, 29.4 % of the respondent experienced 9 -10 pm glare time, 16.9 % of the respondent experienced 11-12 pm glare time, 6.1 % of the respondent are experienced 8-9 pm of glare time and 1.5 % of the respondent are experienced 7 -8 pm of glare time.

Table 4.12: Time of Glare

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	13:00 -14:00	5	1.5	1.5	1.5
	14:00-15:00	20	6.1	6.1	7.7
	15:00-16:00	96	29.4	29.4	37.1
	16:00-17:00	150	46.0	46.0	83.1
	17:00-18:00	55	16.9	16.9	100.0
	Total	326	100.0	100.0	

4.3.1.2. Adaptation of Glare

Table 4.13 shows, that according to the response of the respondent 30.1 % of the respondent are a low level of glare adaptation, 26.7 % of the respondent are a very low level of glare adaptation, 19.9 % of the respondent are a moderate level of adaptation, 18.1 % of the respondent are high level of adaptation and 5.2 % of the respondent are very high level of adaptation are experienced on the road.

Table 4.13: Adaptation level

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	very high adaptation	17	5.2	5.2	5.2
	high adaptation	59	18.1	18.1	23.3
	moderate adaptation	65	19.9	19.9	43.3
	low adaptation	98	30.1	30.1	73.3
	very low adaptation	87	26.7	26.7	100.0
	Total	326	100.0	100.0	

4.3.1.3. Glare Sensitivity

Table 4.14, shows, that from the total of 326 respondents 36.5 % of the respondent are high levels of glare sensitivity, 27.0 % of the respondent are moderate levels of glare sensitivity, 27.0 % of the respondent are high levels of glare sensitivity, 8.6 % of the respondent are low level of glare sensitivity and 0.9 % of the respondent are very high level of glare sensitivity is experienced on the sidewalk.

Table 4.14: The level of glare sensitivity

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	3	0.9	0.9	0.9
	Low	28	8.6	8.6	9.5
	Medium	88	27.0	27.0	36.5
	High	119	36.5	36.5	73.0
	Very High	88	27.0	27.0	100.0
	Total	326	100.0	100.0	

4.3.2. Correlational analysis one-way ANOVA

A one-way ANOVA is used for three or more groups of categorical data, to gain information about the relationship between the dependent and independent variables. Before performing the complete analysis of variance (ANOVA), the following basic assumptions were tested: homogeneity of variance and normality.

Homogeneity of variance

When comparing groups, this assumption can be compared with Levene's test. The Levene test is a test method used to evaluate the toughness of taking equal variations (homogeneity of variance). It examines whether there are significant differences between groups (Berehanu, 2018).

Test of Homogeneity of Variances shows that results of Levene's test; were used to check for variance between two groups, however, in this study the variances are tested for more than 2 groups. The significant value of Levene's test is less than .05; the researcher infers that there are significant differences in the variation of scores across the different groups.

Test of Normality

Denotes the normal distributions of variables when drawn on them it is a normal curve (Cohen et al., 2003). As with other assumptions, if the distribution is not normally scattered, associations and significance tests can be incorrectly estimated. In ANOVA, let's assume that our dependent variable is normally distributed. Therefore, a histogram was employed to see the normality of the data. The Shape of the distributions in appendix G indicates that the data is normal.

Normality assumption skewness and kurtosis were calculated. For a sample size larger than 300 the allowable absolute skewness value is -2 to 2 and the allowable absolute kurtosis value ranges from -7 to +7 (Hair et al., 2010). Table 4.15, shows the skewness and kurtosis value between the allowable ranges. Therefore, we would conclude that our dependent variable is normally distributed in each group.

Table 4.15: Skewness and Kurtosis test

Descriptive Statistics							
	N	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Age	326	2.63	1.231	.136	.135	-1.143	.269
GlareD	326	2.99	1.126	-.145	.135	-.756	.269
GlareT	326	3.71	.873	-.506	.135	.298	.269
GlareS	326	3.80	.964	-.421	.135	-.497	.269
Gadap	326	3.55	1.209	-.416	.135	-.893	.269
Valid N (listwise)	326						

4.3.2.1.Age and Glare sensitivity

Table 4.16, shows the descriptive statistics for each of the age categories on the dependent variable. Participants were divided into five age groups (Group 1: below 25; Group 2: 25-40; Group 3: 40-50; Group 4: 50-65; Group 5: above 65).

Table 4.16: The descriptive statistics for each age category on glare sensitivity

Glare Sensitivity								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
Below 25	78	3.03	.967	.109	2.81	3.24	1	5
25-40	79	3.51	.860	.097	3.31	3.70	2	5
40-50	73	4.05	.664	.078	3.90	4.21	3	5
50-65	79	4.41	.651	.073	4.26	4.55	3	5
Above 65	17	4.82	.393	.095	4.62	5.03	4	5
Total	326	3.80	.964	.053	3.70	3.91	1	5

A one-way ANOVA was conducted to compare the effect of passerby's age on glare sensitivity. The glare sensitiveness of passersby differs across different age levels. ANOVA shows that the effect of age on glare sensitivity was significant, $F(4,321) = 42.798$, $p = .000$. (Table 4.17)

Table 4.17: Analysis of Variance

ANOVA					
Glare Sensitivity					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	105.055	4	26.264	42.798	.000
Within Groups	196.985	321	.614		
Total	302.040	325			

Table 4.18: Test of Homogeneity of Variances

		Levene Statistic	df1	df2	Sig.
Glare Sensitivity	Based on Mean	6.060	4	321	.000
	Based on Median	4.646	4	321	.001
	Based on Median and with adjusted df	4.646	4	288.217	.001
	Based on trimmed mean	6.158	4	321	.000

Levene's Statistic is significant, the equal variance was not assumed. To check for individual differences between groups post hoc comparisons were assessed. Table 4.19 shows there is no mean

significant differences were detected between the age groups of 40-50 to 50-65 years; 50-65 to above 65 years of passers-by. Except for the above other tests indicated that the mean scores were significantly different. The mean differences were significant at the 0.05 level.

Table 4.19: Multiple Comparisons

Dependent Variable: Glare Sensitivity						
(I) Age	(J) Age	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Below 25	25-40	-.481 [*]	.146	.012	-.90	-.07
	40-50	-1.029 [*]	.134	.000	-1.41	-.65
	50-65	-1.379 [*]	.132	.000	-1.75	-1.00
	Above 65	-1.798 [*]	.145	.000	-2.22	-1.38
25-40	Below 25	.481 [*]	.146	.012	.07	.90
	40-50	-.548 [*]	.124	.000	-.90	-.20
	50-65	-.899 [*]	.121	.000	-1.24	-.55
	Above 65	-1.317 [*]	.136	.000	-1.71	-.92
40-50	Below 25	1.029 [*]	.134	.000	.65	1.41
	25-40	.548 [*]	.124	.000	.20	.90
	50-65	-.350 [*]	.107	.013	-.65	-.05
	Above 65	-.769 [*]	.123	.000	-1.13	-.41
50-65	Below 25	1.379 [*]	.132	.000	1.00	1.75
	25-40	.899 [*]	.121	.000	.55	1.24
	40-50	.350 [*]	.107	.013	.05	.65
	Above 65	-.418 [*]	.120	.012	-.77	-.06
Above 65	Below 25	1.798 [*]	.145	.000	1.38	2.22
	25-40	1.317 [*]	.136	.000	.92	1.71
	40-50	.769 [*]	.123	.000	.41	1.13
	50-65	.418 [*]	.120	.012	.06	.77
*. The mean difference is significant at the 0.05 level.						

4.3.2.2. Glare time and glare sensitivity

Table 4.20 shows the descriptive statistics for each time interval category on the dependent variable. The time were divided into five groups (Group 1: 13:00-14:00; Group 2: 14:00-15:00; Group 3: 15:00-16:00; Group 4: 16:00-17:00; Group 5: 17:00-18:00). In this case total level of glare sensitivity with respect to time (mean=3.80).

Table 4.20: The descriptive statistics for each time category on glare sensitivity

Glare Sensitivity								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
13:00-14:00	5	3.00	1.414	.632	1.24	4.76	2	5
14:00-15:00	20	3.80	1.005	.225	3.33	4.27	2	5
15:00-16:00	96	3.59	.901	.092	3.41	3.78	2	5
16:00-17:00	150	3.74	1.000	.082	3.58	3.90	1	5
17:00-18:00	55	4.40	.627	.084	4.23	4.57	2	5
Total	326	3.80	.964	.053	3.70	3.91	1	5

A one-way ANOVA was conducted to compare the effect of glare time on the passerby's glare sensitivity. The glare sensitiveness of passersby differs across different time intervals. An analysis of variance showed that the effect of glare time on glare sensitivity was significant, $F(4,321) = 8.078$, $p = .000$. (Table 4.21)

Table 4.21: Analysis of Variance between glare sensitivity and glare time

ANOVA					
Glare Sensitivity					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	27.624	4	6.906	8.078	.000
Within Groups	274.416	321	.855		
Total	302.040	325			

Table 4.22: Test of Homogeneity of Variances

		Levene Statistic	df1	df2	Sig.
GlareS	Based on Mean	4.876	4	321	.001
	Based on Median	2.215	4	321	.067
	Based on Median and with adjusted df	2.215	4	269.818	.068
	Based on trimmed mean	4.349	4	321	.002

Levene's Statistic is significant, the equal variance was not assumed. To check for individual differences between groups post hoc comparisons were assessed. From table 4.23 the test indicated that the mean score for glare time of 15:00-16:00 was significantly different from 17:00-18:00; 16:00-17:00 was significantly different from 17:00-18:00. The mean differences were significant at .05 levels. However, no significant differences were detected between other time categories.

Table 4.23: multiple comparisons

Dependent Variable: Glare Sensitivity						
(I) GlareT	(J) GlareT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
13:00-14:00	14:00-15:00	-.800	.671	.888	-3.68	2.08
	15:00-16:00	-.594	.639	.963	-3.60	2.42
	16:00-17:00	-.740	.638	.895	-3.76	2.28
	17:00-18:00	-1.400	.638	.426	-4.41	1.61
14:00-15:00	13:00-14:00	.800	.671	.888	-2.08	3.68
	15:00-16:00	.206	.243	.991	-.53	.94
	16:00-17:00	.060	.239	1.000	-.67	.79
	17:00-18:00	-.600	.240	.167	-1.33	.13
15:00-16:00	13:00-14:00	.594	.639	.963	-2.42	3.60
	14:00-15:00	-.206	.243	.991	-.94	.53
	16:00-17:00	-.146	.123	.929	-.49	.20
	17:00-18:00	-.806*	.125	.000	-1.16	-.45
16:00-17:00	13:00-14:00	.740	.638	.895	-2.28	3.76
	14:00-15:00	-.060	.239	1.000	-.79	.67
	15:00-16:00	.146	.123	.929	-.20	.49
	17:00-18:00	-.660*	.117	.000	-.99	-.33
17:00-18:00	13:00-14:00	1.400	.638	.426	-1.61	4.41
	14:00-15:00	.600	.240	.167	-.13	1.33
	15:00-16:00	.806*	.125	.000	.45	1.16
	16:00-17:00	.660*	.117	.000	.33	.99
*. The mean difference is significant at the 0.05 level.						

4.3.2.3. Glare duration and glare sensitivity

Table 4.24 shows the descriptive statistics for the glare duration category on the glare sensitivity. The duration time was divided into five groups (Group 1: Below 15 minutes; Group 2: 15-30 minutes; Group 3: 30-45 minutes; Group 4: 45-60 minutes; Group 5: Above 60 minutes).

Table 4.24: The descriptive statistics for each glare duration category on glare sensitivity

Glare Sensitivity								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
Below 15	38	3.55	1.132	.184	3.18	3.92	1	5
15-30	69	3.46	1.023	.123	3.22	3.71	1	5
30-45	103	3.61	.831	.082	3.45	3.77	2	5
45-60	91	4.20	.833	.087	4.02	4.37	2	5
Above 60	25	4.44	.712	.142	4.15	4.73	3	5
Total	326	3.80	.964	.053	3.70	3.91	1	5

A one-way ANOVA was conducted to compare the effect of glare duration on the passerby's glare sensitivity. The glare sensitiveness of passersby differs across different glare duration. An analysis of variance showed that the effect of glare duration on glare sensitivity was significant, $F(4,321) = 11.696$, $p = .000$. (Table 4.25)

Table 4.25: Analysis of Variance between glare sensitivity and glare duration

ANOVA					
Glare Sensitivity					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	38.420	4	9.605	11.696	.000
Within Groups	263.620	321	.821		
Total	302.040	325			

Table 4.26: Test of Homogeneity of Variances

		Levene Statistic	df1	df2	Sig.
GlareS	Based on Mean	4.113	4	321	.003
	Based on Median	2.329	4	321	.056
	Based on Median and with adjusted df	2.329	4	296.880	.056
	Based on trimmed mean	3.910	4	321	.004

Levene's Statistic is significant, the equal variance was not assumed. To check for individual differences between groups post hoc comparisons were assessed. Table 4.27 shows that the mean score for glare duration of below 15 was significantly different from above 60; 15-30 was significantly different from 45-60 minutes; 15-30 was significantly different from above 60; 30-45 was significantly different from 45-60; 30-45 was significantly different from above 60 minutes. The mean differences were significant at the 0.05 level. However, no significant differences were detected between other glare time duration categories.

Table 4.27: Multiple Comparisons

Dependent Variable: Glare Sensitivity						
(I) GlareD	(J) GlareD	Mean Difference (I- J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Below 15	15-30	.089	.221	1.000	-.55	.73
	30-45	-.059	.201	1.000	-.65	.53
	45-60	-.645*	.203	.024	-1.24	-.05
	Above 60	-.887*	.232	.003	-1.56	-.21
15-30	Below 15	-.089	.221	1.000	-.73	.55
	30-45	-.148	.148	.977	-.57	.27
	45-60	-.734*	.151	.000	-1.16	-.30
	Above 60	-.976*	.188	.000	-1.52	-.43
30-45	Below 15	.059	.201	1.000	-.53	.65
	15-30	.148	.148	.977	-.27	.57
	45-60	-.586*	.120	.000	-.93	-.25

	Above 60	-.828*	.164	.000	-1.31	-.34
45-60	Below 15	.645*	.203	.024	.05	1.24
	15-30	.734*	.151	.000	.30	1.16
	30-45	.586*	.120	.000	.25	.93
	Above 60	-.242	.167	.790	-.73	.25
Above 60	Below 15	.887*	.232	.003	.21	1.56
	15-30	.976*	.188	.000	.43	1.52
	30-45	.828*	.164	.000	.34	1.31
	45-60	.242	.167	.790	-.25	.73
*. The mean difference is significant at the 0.05 level.						

4.3.2.4. Glare adaptation and glare sensitivity

Table 4.28 shows the descriptive statistics for each level of glare adaptation category on the dependent variable. The glare sensitiveness of passersby differs across different adaptation levels. The different adaptation levels were divided into five groups (Group 1: very high adaptation; Group 2: high adaptation; Group 3: moderate adaptation; Group 4: low adaptation; Group 5: very low adaptation).

Table 4.28: The descriptive statistics for each glare adaptation level on glare sensitivity

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
very high adaptation	17	3.12	1.054	.256	2.58	3.66	2	5
high adaptation	59	3.07	1.127	.147	2.77	3.36	1	5
moderate adaptation	65	3.32	.640	.079	3.16	3.48	2	5
low adaptation	98	4.16	.769	.078	4.01	4.32	2	5
very low adaptation	87	4.38	.595	.064	4.25	4.51	3	5
Total	326	3.80	.964	.053	3.70	3.91	1	5

A one-way ANOVA was conducted to compare the effect of glare adaptation on the passerby's glare sensitivity. The glare sensitivity of passersby differs across different glare adaptation levels. An analysis of variance showed that the effect of glare adaptation on glare sensitivity was significant, $F(4,321) = 37.654$, $p = .000$. (Table 4.29)

Table 4.29: Analysis of Variance between glare sensitivity and glare adaptation level

ANOVA					
Glare Sensitivity					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	96.460	4	24.115	37.654	.000
Within Groups	205.579	321	.640		
Total	302.040	325			

Table 4.30: Test of Homogeneity of Variances

		Levene Statistic	df1	df2	Sig.
GlareS	Based on Mean	6.873	4	321	.000
	Based on Median	5.300	4	321	.000
	Based on Median and with adjusted df	5.300	4	289.943	.000
	Based on trimmed mean	6.833	4	321	.000

Levene's Statistic is significant, the equal variance was not assumed. To check for individual differences between groups post hoc comparisons were assessed. Table 4.31 indicated that the mean score for glare adaptation of very high adaptation was significantly different from very low adaptation; the high adaptation was significantly different from low adaptation; the high adaptation was significantly different from very low adaptation; the moderate adaptation was significantly different from low adaptation; the moderate adaptation was significantly different from above very low adaptation. The mean differences were significant at the 0.05 level. However, no significant differences were detected between other glare adaptation levels.

Table 4.31: Multiple Comparisons

Dependent Variable: Glare Sensitivity						
(I) Gadap	(J) Gadap	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
very high adaptation	high adaptation	.050	.295	1.000	-.84	.94
	Normal adaptation	-.205	.268	.995	-1.04	.63
	low adaptation	-1.046*	.267	.009	-1.88	-.21
	Very low adaptation	-1.262*	.263	.001	-2.09	-.43
high adaptation	very high adaptation	-.050	.295	1.000	-.94	.84
	Normal adaptation	-.255	.167	.738	-.73	.22
	low adaptation	-1.095*	.166	.000	-1.57	-.62
	Very low adaptation	-1.312*	.160	.000	-1.77	-.85
Normal adaptation	very high adaptation	.205	.268	.995	-.63	1.04
	high adaptation	.255	.167	.738	-.22	.73
	low adaptation	-.840*	.111	.000	-1.16	-.52
	Very low adaptation	-1.056*	.102	.000	-1.35	-.77
low adaptation	very high adaptation	1.046*	.267	.009	.21	1.88
	high adaptation	1.095*	.166	.000	.62	1.57
	Normal adaptation	.840*	.111	.000	.52	1.16
	Very low adaptation	-.216	.101	.282	-.50	.07
Very low adaptation	very high adaptation	1.262*	.263	.001	.43	2.09
	high adaptation	1.312*	.160	.000	.85	1.77
	Normal adaptation	1.056*	.102	.000	.77	1.35
	low adaptation	.216	.101	.282	-.07	.50
*. The mean difference is significant at the 0.05 level.						

4.3.3. The measure of effect size

Eta-value is part of chi-square under ANOVA analysis; it is a standardized estimate of effect size, meaning that it is comparable across outcome variables measured using different units. Eta-square can be explained as the proportion of variance. Eta range from 0-1 zero means no association one means perfect or strong association.

4.3.3.1. Glare sensitivity with age

Table 4.32 shows, the value of Eta 0.59, which infers that has a strong association between age and glare sensitiveness. Eta square = .35, which means that the independent variable has a 35% effect on the dependent variable outcome.

Table 4.32: the impact of age on Glare sensitivity of passersby

Nominal by Interval	Eta	Glare sensitivity-Dependent	.590
		Age-Dependent	.591

4.3.3.2. Glare sensitivity with glare duration

Table 4.33 shows, the value of Eta 0.357; it infers an association between glare duration and glare sensitivity. Eta square = .13, which means that the independent variable has a 13 % effect on the dependent variable outcome.

Table 4.33: The impact of glare duration on Glare sensitivity of passersby

			Value
Nominal by Interval	Eta	Glare sensitivity Dependent	.357
		GlareD Dependent	.315

4.3.3.3. Glare sensation with glare time

Table 4.34 shows, the value of Eta 0.302; it infers an association between glare time and glare sensitivity. Eta square = .10, which means that the independent variable has a 10 % effect on the dependent variable outcome.

Table 4.34: The impact of glare time on Glare sensitivity of passersby

			Value
Nominal by Interval	Eta	Glare sensitivity Dependent	.302
		GlareT Dependent	.266

4.3.3.4. Glare sensation with glare adaptation

Table 4.35 shows, the value of Eta .565; it infers that has a strong association between glare adaptation and glare sensitivity. Eta square = .32, which means that the independent variable has a 32 % effect on the dependent variable outcome.

Table 4.35: The impact of glare adaptation on Glare sensitivity of passersby

			Value
Nominal by Interval	Eta	Glare sensitivity Dependent	.565
		Gadap Dependent	.565

4.3.4. Discussion

For the driver's visual comfort, the analysis of the result is based on Hassall (1991), the suggested equivalent veiling glare threshold for solar glare assessment is 500cd/m^2 . Later the researcher tries to adjust according to the driver's adaptation state related to the amount of background light the retina receives under static conditions with different sky conditions. (See appendix C). According to Hassel the acceptable allowance illumination for early twilight drivers' adaptation state is about $250\text{-}500\text{cd/m}^2$, ambient horizontal illumination 5000 lux .

The equivalent veiling luminance of all buildings and their time of assessment are within the acceptable range as the veiling glare caused by the reflection is within the recommended limit (500cd/m^2) and therefore it is unlikely to cause glare.

Table 4.36: Equivalent veiling luminance of the buildings at different times of day

Buildings	Time	equivalent veiling luminance (cd/m^2)	veiling glare threshold
Awash bank and insurance Sc.	4:00 pm	360.96	500
	4:30 pm	361.95	500
	5:00 pm	413.19	500
Churchill Hotel	4:00 pm	214.98	500
	4:30 pm	225.05	500
	5:00 pm	223.31	500
NOC	4:00 pm	175.38	500
	4:30 pm	240.77	500
	5:00 pm	226.28	500
Eshetu Mamo commercial center	4:00 pm	244.44	500
	4:30 pm	323.25	500
	5:00 pm	235.66	500
Dirar mall	4:00 pm	336.01	500
	4:30 pm	374.69	500
	5:00 pm	335.55	500

For the nearby occupant's visual comfort, the analysis is based on the Sydney City Council of buildings standard. According to (Rofail et al., 2004) The maximum level of average reflectivity that bounces off from the building's exterior envelope must not exceed 20% of the incident ray.

According to the findings of the study, the maximum reflectance was measured in Eshetu Mamo commercial center which is 47.64 %, and the minimum reflectance of the façade is obtained in Dirar mall which is 31.56%. However, all of the measured daily average reflected rays are greater than the maximum allowable threshold. Therefore we can conclude that there is discomfort glare pollution or there is an adverse impact on the occupants of neighboring residents.

Table 4.37: Average measured incident light and reflected glare in lux (lm/m²) for all building

Buildings	Average incident (LUX)	Average reflected (LUX)	Average % reflection
Awash bank and insurance Sc.	19920	9260	46.49
Churchill Hotel	16760	7428	44.35
National oil Ethiopia	16760	6266	43.73
Eshetu Mamo commercial center	17640	8406	47.64
Dirar mall	20000	6312	31.56

According to the result of pedestrians' visual comfort, 326 participants were asked. For measuring the glare sensitivity perception an adapted version of the instrument (Ishak et al., 2019) was used. This measurement consisted of a questionnaire that was filled in participants looking at the buildings. The sensitivity variation is depending on age category, glare time interval, glare duration range, and glare adaptation level. Four independent variables have been defined in the studies which are age, glare time, glare duration, and glare adaptation.

The test of homogeneity and test of normality shows that the survey questionnaire is a reliable method to measure glare sensitivity from the predictors. The result shows that the test of homogeneity of Levene's Statistic is significant, the equal variance was not assumed. The test of normality shows that the dependent variable is normally distributed in each group.

The ANOVA result shows that glare sensitivity across different age groups differs significant $F(4,321) = 42.798$, $p = .000$. However, no significant differences were detected between 40-50 years ($M = 4.05$, $SD = .664$) and 50-60 years ($M = 4.41$, $SD = .651$); between 50-60 years ($M = 4.41$, $SD = .651$) and above 65 years 50-60 years ($M = 4.82$, $SD = .393$). Whereas, except for the above age category the other all age categories was significant differences in glare sensitivity across age groups. Eta square = .35, which means that age has a 35% effect on the glare sensitivity outcome.

The ANOVA test shows that glare sensitivity across different time intervals differs significant $F(4,321) = 8.078, p = .000$. The test indicated that the mean score for glare time of 15:00-16:00 ($M = 3.59, SD = .901$); was significantly different from 17:00-18:00 ($M = 4.40, SD = .627$); 16:00-17:00 ($M = 3.74, SD = 1.00$); was significantly different from 17:00-18:00 ($M = 4.40, SD = .627$). However, no significant differences were detected between other glare time categories. Eta square = .13, which means that Glare time has a 13 % effect on the glare sensitivity outcome.

An analysis of variance showed that the effect of glare duration on glare sensitivity was significant, $F(4,321) = 11.696, p = .000$. The ANOVA test indicated that the mean score for glare duration of below 15 ($M = 3.74, SD = 1.00$) was significantly different from above 60 ($M = 4.44, SD = .712$); 15-30 ($M = 3.46, SD = 1.023$) was significantly different from 45-60 minute ($M = 4.20, SD = .833$); 15-30 ($M = 3.46, SD = 1.023$) was significantly different from above 60 minute ($M = 4.44, SD = .712$); 30-45 ($M = 3.61, SD = .831$) was significantly different from 45-60 ($M = 4.20, SD = .833$); 30-45 ($M = 3.61, SD = .831$) was significantly different from above 60 ($M = 4.44, SD = .712$) minute. The mean differences were significant at the 0.05 level. However, no significant differences were detected between other glare time duration categories. Eta square = .10, which means that Glare duration has a 10 % effect on the glare sensitivity outcome.

An analysis of variance showed that the effect of glare adaptation on glare sensitivity was significant, $F(4,321) = 37.654, p = .000$. The ANOVA test indicated that the mean score for glare adaptation of very high adaptation ($M = 3.12, SD = 1.054$) was significantly different from Very low adaptation ($M = 4.38, SD = .595$), high adaptation ($M = 3.07, SD = 1.127$) was significantly different from low adaptation ($M = 4.16, SD = .769$), high adaptation ($M = 3.07, SD = 1.127$) was significantly different from Very low adaptation ($M = 4.38, SD = .595$), Normal adaptation ($M = 3.32, SD = .640$) was significantly different from low adaptation ($M = 4.16, SD = .769$), Normal adaptation ($M = 3.32, SD = .640$) was significantly different from above Very low adaptation ($M = 4.38, SD = .595$). The mean differences were significant at the 0.05 level. However, no significant differences were detected between other glare adaptation levels. Eta square = .32, which means that glare adaptation has a 32 % effect on the glare sensitivity outcome.

The level of glare sensitiveness caused by a solar glare that bounces off from the selected buildings, the perception of passersby the mean score is 3.80. According to passersby, there is glare pollution in the walkway.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1.CONCLUSION

Highly glazed façades have almost become a modern architecture standard in the last few decades. Architects prefer glass curtain walls as the building envelope, to achieve the goal of saving energy and reducing cooling load, providing daylight, reducing the dead load of the building, etc. Solar reflection studies are becoming increasingly important as architectural designs become more complex in shape and geometry. However, in Ethiopia, there are no industry-wide accepted regulations concerning solar reflections in the built environment. As a result, architects have almost no guidance on how to prevent their designs from unwanted thermal or visual impacts on the outdoor environment. Considering the significant risks of discomfort caused by solar reflectance, the problem needs to be resolved during the design phase.

This study aims to assess the Impact of glare pollution from the existing building facades in Addis Ababa in the outdoor environment. Further, to analyze the solar reflection phenomenon, the assessment was done based on the impacts of the solar reflection on drivers, nearby occupants, and the perception of passersby.

To get the intensity of veiling glare, a Lux meter is used to measure the reflected glare illuminance of the buildings. The measurement was done three times a day on a different day in March. Reflected Solar illuminance of all five buildings at their façade, the vertical and horizontal angles between the glare source and the driver's position, and the distance between them at the road were recorded. By using Holladay's general formula the veiling glare luminance of each building in each time and position was calculated and compared with Hassel's veiling glare threshold, The equivalent veiling luminance of all buildings at their time of assessment is within the acceptable range as the veiling glare caused by the reflection is within the recommended limit (500cd/m^2) and therefore it is unlikely to cause glare.

To assess the discomfort glare for nearby occupants of the selected buildings, a lux meter is used to measure the illuminance of reflected solar rays from the selected building façade to the neighboring areas. The measurement was done 5 times a day for each building. From the nearby building that

occur the reflected solar ray trespass area the reflected solar light illuminance, as well as the direct solar illuminance, were recorded. The analysis was based on the Sydney City Council of buildings standard, the maximum allowable level of the illuminance of the reflection that bounces off from the building's façade must not exceed 20% of the incident ray illuminance. The calculation was done and compared to the maximum allowable threshold, the results show that the measured average illuminations of reflected rays are greater than that of the maximum allowable threshold. So the conclusion is that there was discomfort glare occurring at the occupants of a neighboring building.

To get the perception of passers-by in the selected area, the questionnaires were prepared and distributed to 357 respondents and 326 valid responses participated. The survey was analyzed based on different independent variables and dependent variables. The independent variables are (age, glare time, glare duration, and glare adaptation,) and the dependent variable was glare sensitivity which evaluates the general perception of passers-by. A one-way ANOVA test was done to gain information about the relationship between the dependent and independent variables. The result shows that the effect of age on glare sensitivity was significant, $F(4,321) = 42.798$, $p = .000$, and the effect of glare time on glare sensitivity was significant, $F(4,321) = 8.078$, $p = .000$. The effect of glare duration on glare sensitivity was significant, $F(4,321) = 11.696$, $p = .000$ and effect of glare adaptation on glare sensitivity were significant, $F(4,321) = 37.654$, $p = .000$. Age has 35%, glare time has 13 %, glare duration has 10 % and glare adaptation has 32 % effect on the glare sensitivity outcome.

5.2. RECOMMENDATION

This final section of the study proposes recommendations for further studies, regarding solar reflectivity and green buildings, for environmental sustainability.

1. In Ethiopia, there are no industry-wide accepted regulations concerning solar reflections in the built environment. To reduce the issue of unwanted solar reflectivity, adapt other countries' standards to develop solar reflectivity regulations and laws.
2. The impact of solar reflectance on the natural environment like fauna and flora in addition to human beings should be studied by a different organization that works on environmental protection.
3. For architects, designers and researchers, it is recommended to be engaged in the comprehensive study of solar reflectivity before decisions on major facade elements design.

4. For architects, during the designing process, the material selection of building envelopes shall be avoided as highly reflective or specular materials.
5. During the designing process consider the building is oriented to minimize solar exposure from east and west and maximize south and north-facing facade area. Solar exposure occurs in critical hours at East and west in most cases.
6. To prevent the reflected glare, it is recommended to replace the smooth surface with diffuse surfaces.
7. Considering the orientation of the building should be North West / South East for the long facades.
8. Architects can also recommend their clients to use natural resources, more long-lasting materials, or easily replaceable products for constructing their buildings. This would mean recommending clients to develop green buildings. The Architects, Planners, Engineers, and associates should be the ones to determine their client's desire for natural buildings, by making them understand the advantages of these types of constructions.

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APPENDIX

Appendix A: The checklist that was used for the selection of the sample buildings

Building name _____

Building Height _____

Construction date _____

Building skin _____

Building location _____

Building Function _____

Architect _____

Building mass _____

	Orientation of the building	Remark
1.	South faced	
2.	Southwest faced	
3.	West faced	
4.	East faced	
5.	Southeast faced	
6.	North faced	
7.	Northwest faced	
8.	Northeast faced	

No	Glare nuisance on outdoor environment	Yes	No
1.	Does the building reflect on the road?		
2.	Does the building reflect on the sidewalk?		
3.	Does the building material reflected in the nearby occupants' area? (home, shops, workplaces, etc.)		

Appendix B- Pedestrian counting form**Appendix B1- Pedestrians counting form of Awash bank and insurance sc**

Awash bank and insurance sc	Day	Time	Counts
	23/02/2022	5:00pm-6:00pm	778
	24/02/2022	5:00pm-6:00pm	783
	25/02/2022	5:00pm-6:00pm	796
	26/02/2022	5:00pm-6:00pm	715
	27/02/2022	5:00pm-6:00pm	687
	28/02/2022	5:00pm-6:00pm	858
	01/3/2022	5:00pm-6:00pm	724
	total		763

Appendix B2- Pedestrians counting form of Churchill Hotel

Churchill Hotel	Day	Time	Counts
	23/02/2022	5:00pm-6:00pm	730
	24/02/2022	5:00pm-6:00pm	791
	25/02/2022	5:00pm-6:00pm	788
	26/02/2022	5:00pm-6:00pm	586
	27/02/2022	5:00pm-6:00pm	645
	28/02/2022	5:00pm-6:00pm	769
	01/3/2022	5:00pm-6:00pm	736
	total		721

Appendix B3- Pedestrians counting form of National Oil Ethiopia

National oil Ethiopia	Day	Time	Counts
	23/02/2022	5:00pm-6:00pm	684
	24/02/2022	5:00pm-6:00pm	671
	25/02/2022	5:00pm-6:00pm	689
	26/02/2022	5:00pm-6:00pm	586
	27/02/2022	5:00pm-6:00pm	592
	28/02/2022	5:00pm-6:00pm	531
	01/3/2022	5:00pm-6:00pm	734
	total		641

Appendix B4- Pedisterians counting form of Eshetu Mamo commercial center

Eshetu Mamo commercial center	Day	Time	Counts
	23/02/2022	5:00pm-6:00pm	723
	24/02/2022	5:00pm-6:00pm	611
	25/02/2022	5:00pm-6:00pm	638
	26/02/2022	5:00pm-6:00pm	624
	27/02/2022	5:00pm-6:00pm	492
	28/02/2022	5:00pm-6:00pm	657
	01/3/2022	5:00pm-6:00pm	710
	total		636

Appendix B5- Pedisterians counting form of Dirar mall

Dirar mall	Day	Time	Counts
	23/02/2022	5:00pm-6:00pm	671
	24/02/2022	5:00pm-6:00pm	629
	25/02/2022	5:00pm-6:00pm	639
	26/02/2022	5:00pm-6:00pm	664
	27/02/2022	5:00pm-6:00pm	452
	28/02/2022	5:00pm-6:00pm	412
	01/3/2022	5:00pm-6:00pm	613
			583

Appendix C: Typical driver's adaptation state for different background lighting conditions, the driver's adaptation state can be defined as the amount of background light the retina receives under static conditions(Schieber et al., 1998)

Background Lighting Condition	Driver's Adaptation State (cd/m ²)	Ambient Horizontal Illumination (lux)
Road at night	1-5	100
Late twilight/ early dawn	50	500
Early twilight / late dawn	250-500	5000
Overcast daytime sky	1000	10,000
Clear winter day	500-1500	30,000
Bright summer day	5000-6000	85,000 +



Appendix D: Questionnaires
Adama Science and Technology University Office of graduate studies
Department of Environmental Architecture

Dear respondents,

Thank you for taking the time to fill out this questionnaire. These survey questions are a research instrument for the fulfillment of my MSc program in the field of Environmental Architecture at Adama Science and Technology University, the study is focused on the Assessment of the Impact of glare pollution from the existing building facades in Addis Ababa. Your response will be completely anonymous and confidential, and will not be identified by an individual. All responses will be compiled together and analyzed as a group.

Dear respondent, please do not hesitate to contact me for any difficulty and /or clarification while you are filling out this questionnaire.

1. Gender

A. Male ☐

B. Female ☐

2. Age

20 – 30 ☐

41 – 50 ☐

> 60 ☐

31 – 40 ☐

51 – 60 ☐

3. At which time of the day did discomfort glare was occurred on the sidewalk?

7:00 pm – 8:00 pm ☐

10:00 pm – 11:00 pm ☐

8:00 pm – 9:00 pm ☐

11:00 pm – 12:00 pm ☐

9:00 pm – 10:00 pm ☐

4. Please specify the duration of glare that you experience on the sidewalk

Below 15 minutes ☐

45-60 minutes ☐

15-30 minutes ☐

Above 60 minutes ☐

30-45 minutes ☐

5. Please specify your glare adaptation level.

Very high adaptation ☐

Low adaptation ☐

High adaptation ☐

Very low adaptation ☐

Moderate adaptation ☐

6. Please specify your glare sensitivity level on the sidewalk

Very low ☐

Medium ☐

Very High ☐

Low ☐

High ☐



Appendix E: Amharic Questionnaire Paper

የአዳማ ሳይንስና ቴክኖሎጂ ዩኒቨርሲቲ የድህረ ምረቃ ትምህርት ቤት

አርክቴክቸር ዲፓርትመንት

ውድ ምላሽ ሰጪ፣

ይህን መጠይቅ ለመሙላት ጊዜ ስለወሰዱ እናመሰግናለን። እነዚህ የዳሰሳ ጥያቄዎች በአዳማ ሳይንስና ቴክኖሎጂ ዩኒቨርሲቲ በ ኢንቨሮመንታል አርክቴክቸር ማስተርስ ሳይንስ ዘርፍ ፕሮግራም የመመረቂያ ጽሁፍ ለማዘጋጀት የሚያገለግሉ የምርመራ መሳሪያ ናቸው። “Assessment of the Impact of glare pollution from the existing building facades in Addis Ababa” በሚል ርዕስ ለማካሄድ ጥናት የ እግረኞች መንገድ ላይ በሕንፃዎች ነጸብራቅ ዙሪያ ያላቸውን ሃሳብ ወይም ስሜት በመጠየቅ፣ ለጥናቱ እንደ ግባት ለመውሰድ የተዘጋጀ ፎርም ነው። ስለሆነም እባክዎትን የተጠየቁ ጥያቄዎችን በአንክሮ በማንበብ፣ ለምርጫ ጥያቄዎች መልስ የምትሏቸው (√ ወይም X) በመምረጥና በተቀመጠው ክፍት ቦታ እንድትሞሉልን በትህትና እንጠይቃለሁ።

ምላሽዎ ሙሉ በሙሉ የሚይታወቅ እና ሚስጥራዊ ይሆናል። ሁሉም ምላሾች አንድ ላይ ተሰብስበው በቡድን ይተነተናሉ።

ውድ ምላሽ ሰጪ፣ እባክዎን ይህንን መጠይቅ በሚሞሉበት ጊዜ ለማንኛውም ችግር ወይም ማብራሪያ እኔን ለመጠየቅ አያቅማሙ።

1. ጾታ

ወንድ ☐

ሴት ☐

2. ዕድሜ

ከ25 በታች ☐

40 – 50 ☐

ከ 65 በላይ ☐

25 – 40 ☐

50 – 65 ☐

7. በዚህ መንገድ ሲጓዙ በህንጻው አንፀባራቂነት ምክንያት በየትኛው ሰዓት ላይ የእይታ ምችት ማጣት አጋጥሞዎታል?

7:00 – 8:00 ከሰአት ☐

10:00 – 11:00 ከሰአት ☐

8:00 – 9:00 ከሰአት ☐

11:00 – 12:00 ከሰአት ☐

9:00 – 10:00 ከሰአት ☐

8. በዚህ መንገድ ሲጓዙ ለምን ያክል ደቂቃ ከህንጻው በሚመጣው ፅብረቃ ተጋላጭ ሆነዋል?

ከ 15 ደቂቃዎች በታች ☐

45-60 ደቂቃዎች ☐

15-30 ደቂቃዎች ☐

ከ 60 ደቂቃዎች በላይ ☐

30-45 ደቂቃዎች ☐

9. አንፀባራቂ ነገሮችን በምን ያክል ደረጃ ለምደዋል?

በጣም ከፍተኛ መላመድ ☐

ዝቅተኛ መላመድ ☐

ከፍተኛ መላመድ ☐

በጣም ዝቅተኛ መላመድ ☐

መጠነኛ መላመድ ☐

10. በዚህ ህንጻ አንፀባራቂነት ምክንያት የሚሰማዎትን የእይታ መረበሽ ወይም ምችት የማጣት ደረጃ ይግለጹ

በጣም ዝቅተኛ ☐

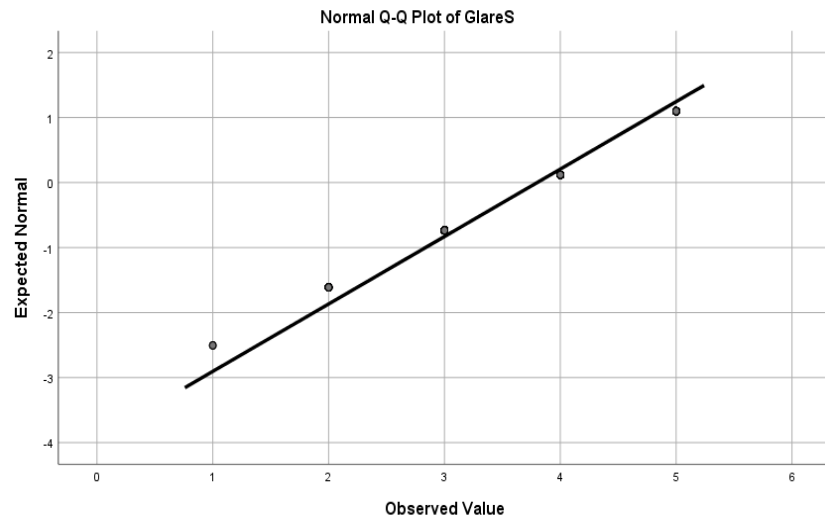
ከፍተኛ ☐

ዝቅተኛ ☐

በጣም ከፍተኛ ☐

መካከለኛ ☐

Appendix G: Normal P-P Plot the dependent variable measures score



Appendix H: The collected data at Awash bank and insurance SC

8/3/2022	Time	E	VD	HD	α	Point
	4:00 PM	8710	18.6	73.5	6.50	p1
	4:30 PM	7950	17.4	74.4	7.00	p2
	5:00 PM	5190	10.1	72.3	8.00	p3

Appendix I: The collected data at Churchill Hotel

8/3/2022	Time	E	VD	HD	α	Point
	4:00 PM	9380	16.6	65.4	16.00	p1
	4:30 PM	7240	11.9	64.2	15.00	p2
	5:00 PM	6230	10.8	68.9	14.50	p3

Appendix J: The collected data at NOC

11/3/2022	Time	E	VD	HD	α	Point
	4:00 PM	7630	16.6	71.3	17.20	p1
	4:30 PM	6790	12.7	73.4	14.00	p2
	5:00 PM	5170	10.3	80.2	13.50	p3

Appendix K: The collected data at Eshetu Mamo commercial

13/03/2022	Time	E	VD	HD	α	Point
	4:00 PM	9510	16.56	75.7	16.00	p1
	4:30 PM	8190	10.24	71.6	14.00	p2
	5:00 PM	7210	9.29	76.7	16.50	p3

Appendix L: The collected data at Dirar mall

20/03/2022	Time	E	VD	HD	α	Point
	4:00 PM	8260	17.17	84.8	11.00	p1
	4:30 PM	8540	15.38	86.5	11.50	p2
	5:00 PM	6580	10.93	82.3	12.00	p3