INFLUENCE OF VERTICAL EYE ILLUMINANCE ON WORKERS' VISUAL COMFORT IN GREEN INDUSTRIAL LANDSCAPE SPACES: CASE STUDY FROM THE TEXTILE FACTORY IN SRI LANKA

GAMAGE T.G.A.S.[1]* & DHARMASENA S.R.[2]
[1,2]University of Moratuwa, Moratuwa, Sri Lanka
[1]gamagetgas.21@uom.lk, anushadi.sachinthani01@gmail.com, [2]shameend@uom.lk

Abstract: This research investigates the influence of vertical eye illuminance in the visual comfort of workers in green industrial landscapes in the context of the textile and apparel sectors in Sri Lanka. Industrialization is a part of economic development, and the textile industry is a major player in the economy of Sri Lanka. Green industrial landscape spaces create environmental responsibility and support the well-being of workers by providing better outdoor lighting. Utilizing a mixed-methodology system consisting of behavioral mapping, photographic recording, and in-situ illuminance readings by lux meters, this research assesses the levels of visual comfort in different areas of a green-certified textile production facility. The major outcomes indicate that vertical eye illuminance highly varies from space and time and hence affects the workers' level of comfort. This research deepens the understanding of outdoor visual comfort in the context of industries for the implementation of sustainable workplace design for the improvement of employee welfare and productivity.

Keywords: *Vertical Eye Illuminance, Green Industrial Landscape, Textile and Apparel Industry, Visual Comfort.*

1. Introduction

Industrialization is crucial for any country's development. It boosts economic growth, creates jobs, reduces poverty, and supports infrastructure development (Karunarathne, 2019). The textile and apparel industry functioning as one of the nation's most significant contributors to GDP, export revenue, and employment (Export Development Board (EDB), Sri Lanka, 2024). As global manufacturing shifts toward sustainability and worker-centered design, the integration of green industrial landscapes has gained prominence in Sri Lanka's textile sector.

Within these outdoor industrial environments, visual comfort emerges as a crucial factor influencing workers' relaxation, stress reduction, and spatial usability during break periods. Previous literature emphasizes that lighting is a key determinant of visual comfort, with vertical eye illuminance being particularly relevant because it directly represents the light entering the human eye and shaping visual perception, alertness, and comfort (Suk, 2018). However, studies on lighting in industrial settings have predominantly focused on indoor workspaces. Outdoor lighting in green industrial landscapes remains critically understudied, especially in tropical South Asian manufacturing contexts, where natural daylight varies sharply across the day.

The gap becomes more evident considering that workers in textile factories typically access outdoor landscape areas during fixed break times in the morning, afternoon and evening exposing them to fluctuating illuminance levels caused by direct sun, shading patterns, and reflectance from built structures. If vertical eye illuminance is either too high, causing glare and discomfort or too low, reducing visual clarity and spatial safety. The intended benefits of green industrial spaces may not materialize.

Thus, the lack of research on optimal outdoor lighting conditions within industrial landscapes limits the development of evidence-based design guidelines for worker welfare. This study is therefore justified on two fronts:

1) Current lighting and human comfort literature highlights the importance of vertical eye illuminance but lacks application in outdoor industrial landscapes, particularly in tropical countries.
2) As Sri Lankan textile factories adopt green certifications such as LEED and GREENSL®, data-driven lighting improvements are essential to enhance worker experience, safety, and productivity.

Research Objectives

1. To measure vertical eye illuminance levels in different green industrial landscape spaces within a textile factory.
2. To analyze how these illuminance levels vary across time periods typically used by workers (morning, afternoon and evening).
3. To evaluate the relationship between vertical eye illuminance and workers perceived visual comfort.

*Corresponding author: Tel: +94 724179351 Email Address: gamagetgas.21@uom.lk, anushadi.sachinthani01@gmail.com
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Research Question

How does vertical eye illuminance influence workers' visual comfort in green industrial landscape spaces within a textile factory in Sri Lanka?

2. Literature Review

2.1 HISTORICAL DEVELOPMENT OF INDUSTRIALIZATION

During the First Industrial Revolution, Sri Lanka (then Ceylon) was under Dutch colonial rule, which boosted exports of spices, cinnamon, coffee, and tobacco by developing infrastructure like canals and ports. (Dewanarayana & Wilmalarathane, 2023)

After gaining independence in 1948, Sri Lanka's economy was largely based on agriculture, especially plantations of tea, rubber, and coconut, which made up about 90% of foreign exchange earnings. This called as the Second Industrial Revolution (Dewanarayana & Wilmalarathane, 2023; Karunarathne, 2019). The Third Industrial Revolution, During the 1960s and 1970s, Sri Lanka adopted import substitution industrialization (ISI) policies, leading to the establishment of basic industries such as textiles, cement, and chemical production (Board of investment of sri lanka, 2024). A major turning point came in 1977, when a new government introduced sweeping economic reforms to liberalize trade, encourage foreign investment, and shift towards export-oriented industrialization (EOI) (Karunarathne, 2019; Kumararatne, 2021). Export Processing Zones (EPZs) were established, especially in textiles and labour-intensive industries (Dewanarayana & Wilmalarathane, 2023).

2.2 CLASSIFICATION OF INDUSTRIES IN SRI LANKA

Sri Lanka's industrial sector encompasses both traditional and modern industries. (Dewanarayana & Wilmalarathane, 2023). It is broadly classified into three main sectors, aligned with international standards such as the International Standard Industrial Classification (ISIC) framework. The following table 1 provide a clear overview of these industry types, organized and presented by the author.

Table 1: Classification of Industries in Sri Lanka
(*Source: Export Development Board (EDB), Sri Lanka, 2024; Ministry of industries, 2022; Central bank of Sri Lanka, 2023*)

Primary industries	Secondary industries	Tertiary industries
- Agriculture, forestry, and fishing (Focuses on tea, rubber, coconut, paddy, spices, and fisheries.) - Mining and quarrying (Includes graphite mining, mineral sands extraction, limestone, clay, and stone quarrying.)	*A) factory industries:* **- Textiles and Apparel (largest contributor)** - Food, beverages, and tobacco - Rubber and plastics - Chemical and chemical products - Basic metal products *B) small-scale and cottage industries:* - Handloom, coir products, woodcraft, batik, and handicrafts *C) construction industry:* - Residential, non-residential buildings, infrastructure	Electricity, gas, steam, and air conditioning supply Water supply; sewerage, waste management, and remediation activities Transportation and storage Wholesale and retail trade Information and communication Financial and insurance activities Tourism and hospitality industry

The industrial sector is broadly divided into three categories: Agriculture, services, and manufacturing. The textile and apparel industry falls under manufacturing and holds a prominent place within this sector (Gunathilake & De Mel, 2016).

2.3 TEXTILE AND APPAREL SECTOR

The textile and apparel sector is the largest industrial contributor to Sri Lanka's export economy. (Board of investment, srilanka, 2022). According to the Factory Industry Production Index (FIPI), it consistently leads factory production in the country (Embuldeniya, 2015). Within the broader industrial sector, the textile and apparel industry plays a major role, providing jobs to over 15% of Sri Lanka's workforce and contributing more than 40% to the country's industrial exports (Central Bank of Sri Lanka, 2020). Sri lanka has built a strong reputation as a reliable clothing manufacturer for leading global brands such as nike, victoria's secret, gap, and marks & spencer. The industry is also known for its focus on ethical and environmentally friendly practices, proudly operating under the motto "garments without guilt" (Gunathilake & De Mel, 2016).

2.4 COMPONENTS OF APPAREL INDUSTRY

As per the Export Development Board (EDB), Sri Lanka, (2024), the Sri Lankan garment industry is known for its strong focus on ethical and sustainable practices, following its guiding principle of "Garments without Guilt." Based on this and when reviewing research articles, three main components of the Apparel Industry can be identified as below.

2.4.1 Garment Factories/ Buildings

As awareness grew, apparel industry began taking responsibility for reducing environmental harm. One key approach is Building Green Factories (GFs), factories designed to use resources efficiently and provide healthier work environments (Thilakarathna & De Silva, 2012).

2.4.2 Workers

In the apparel industry, workers also play a very important role ensuring a responsible clothing production through protecting workers' rights, providing education and personal development opportunities, and contributing to poverty reduction within local communities.

2.4.3 Industrial Landscape

According to John Butow, outdoor brands because of their reputation for caring about nature are in a good position to lead the way in making their entire supply chains more sustainable and encourage other clothing brands to follow (Lindahl, 2019). The outdoor spaces around industrial buildings can be seen as secondary work and living areas that work together with the indoor spaces (Zhang et al., 2021).

2.5 GREEN INDUSTRIAL LANDSCAPE

Currently, there is no universally accepted definition for "green industrial landscapes. "However, understanding this concept can be approached by examining the individual notions of green industries and industrial landscapes. By synthesizing these perspectives, a preliminary conceptualization of a " green industrial landscape" can be developed, which integrates ecological principles within industrial spatial contexts.

According to the Zhang et al., (2021), Industrial landscapes are the outdoor spaces around factories or industrial buildings. And also, According to Luud et al., (2003), Industrial landscapes refer to the areas shaped by human industrial activities, where natural features are combined with man-made forms. Green Industries are, Industries that provide goods and services aimed at reducing negative environmental impacts. This includes sectors such as renewable energy, environmental technology, waste management, and energy efficient solutions (Grillitsch & Teis H., 2019).

2.6 GREEN INDUSTRIAL LANDSCAPE SPACES

In the Sri Lankan textile and apparel industry, many factories follow recognized green certification systems, both local and international, such as GreenSL and LEED. By reviewing the official reports and guidelines published by these certification bodies, it is possible to identify key criteria relevant to sustainable design, along with the potential for landscape interventions. The following table highlight specific landscape spaces where sustainable solutions can be applied, supporting environmental performance, worker well-being, and overall site sustainability.

Table 2: Green Industrial Landscape Spaces
(Source: Alwis et al., 2018; Council, 2019; Green building council of Sri Lanka, 2013; Green building council of Sri Lanka 2022)

Criteria	Description	Applicability of Green Industrial Landscape Spaces	Suggested GIL Spaces
1. Management	It involves the use of a skilled team for effective project management as well as the adoption of sustainable practices for construction.	No	-

2.Sustainable Site	Reduce the negative impacts on the environment, protecting ecosystems, and improving the natural landscape's quality by using sustainable landscape design and thoughtful site selection.	Yes	Soil stability and erosion control
			Parking Lots
			Vegetation Cover/ Protection of native vegetation
			Rooftop & Non-rooftop Gardens
3.Water Efficiency	Reduction of the use of potable water through the incorporation of water-conserving vegetation species, water-saving irrigation technologies, and water reuse technologies.	Yes	Water efficient Landscape Spaces
4.Energy Atmosphere	Facilitating the effective operation of the building systems for energy, water, and general usability, while also reducing greenhouse emissions.	No	-
5.Materials, Resources & Waste	Minimizing waste, pollution, and landfill usage by what gets reused and recycled, encouraging renewable resources, local economies, and turning industrial and construction waste into meaningful uses.	No	-
6.Indoor Environmental Quality	Providing for high indoor air quality and occupant comfort by reducing exposure to tobacco smoke and airborne viruses, providing for thermal comfort, and access to natural lighting and views up to the outdoors.	No	-
7.Innovation & Design	Integrate innovative steps which transcend the current standards of the environment and ensure sustainability using novel methods.	Yes	Vertical Gardens / Forest - integrated courtyards
8.Social & Cultural Awareness	Promote cultural identity, community engagement, social equality, and user well-being in the built environment.	Yes	Naturally ventilated spaces
			Recreational and gathering spaces

2.7 VISUAL COMFORT

Visual comfort depends on multiple factors, including lighting conditions, the type of space, the task being done, and occupant characteristics such as age, gender, culture, and behaviour (Hu, 2025).

Visual comfort means how the people feel being relaxed and comfortable when looking at their surroundings. According to Dhayal & Jha, (2023), visual comfort is a complex and subjective concept. Experts have different views, making it hard to define clearly. However, Dolnikova & Katunsky, (2019) describe, visual comfort as a state in which the eyes and mind feel relaxed and function efficiently while observing the surroundings. Hopkinson (1963) and Hu, (2025), simply define visual comfort as the absence of discomfort in vision.

2.8 FACTORS AFFECTING ON OUTDOOR VISUAL COMFORT

According to Tekce et al., (2020), Outdoor visual comfort is the important part for human visual comfort. Ensuring outdoor visual comfort means creating spaces where,

1. Sunlight and shade are well balanced,
2. Surfaces do not cause uncomfortable glare, and there's enough light during darker times of the day.

In the multifaceted realm of visual comfort, the interplay of factors such as brightness, light distribution, shadows, reflections, glare, and colour quality significantly influences the perception of luminous environments, underscoring the need for comprehensive assessments. (Dhayal & Jha, 2023).

This means that daylight is the key component of outdoor visual comfort. According to the referenced documents, the factors affecting visual comfort can be shown as follows (Figure 01).

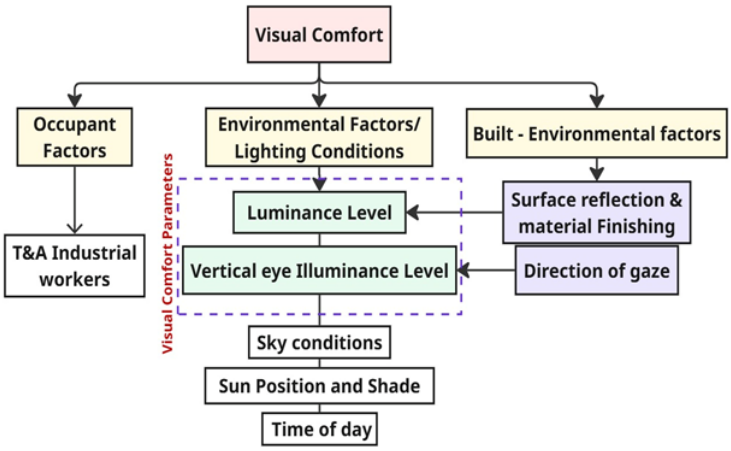


Figure 1 : Selected Visual Comfort Parameters and Their Factors
(*Source: Dhayal & Jha, 2023; Hu, 2025; Marty et al., 2015; Penacchio et al., 2021; Suk, 2018; Tekce et al., 2020; Wijewardane et al., 2018*)

In this research, the focus is specifically on how vertical eye illuminance influence visual comfort.

2.8.1 Vertical eye illuminance
Vertical eye illuminance (in lux) refers to the amount of light that falls directly onto the vertical plane of a person's eyes (Suk, 2018). It is measured by positioning the lux meter at eye level, facing forward in the direction a person would naturally look. This simulates the lighting intensity perceived by the human eye.

3. Methodology

3.1. DATA COLLECTION
For data collection, a mixed-methods approach was adopted to align with the research objectives (ROs). Base on that process is divided into two phases.

Phase 01 - Site Analysis and hotspots identification
1. Behavioural mapping - To identify the user movement and views points
2. Photographic documentation - To records in order to visually record spatial and environmental properties

Phase 02 - Data Collection
Quantitative Data Gathering at this stage, in place readings were also done using a lux meter in an assessment of the levels of illuminance in specifically chosen viewpoints of spaces.

3.2 SITE SELECTION
For the case study, the site was chosen which has earned Green Building certifications a few times and shows a remarkable dedication towards green industrial practices. Due to organizational policies and confidentiality agreements, the name and specific details of the factory cannot be disclosed in this paper.

4. Data Analysis and Findings

Under this section, the analysis will be conducted by using systematic observational data and statistical measurements of illuminance levels to assess visual comfort conditions within the selected spaces.

The Figure 2 below shows the Green Industrial Landscape spaces identified as having the highest potential and being visually connected to employees' daily routines.

Based on that, two main green industrial landscape spaces can be identified.

1. Social & Cultural Space
2. Vegetation Cover

Figure 2 : Identified Green industrial landscape spaces (*Source*: *Compiled by Author*)

These are further divided into sub-spaces to support the study and improve clarity.

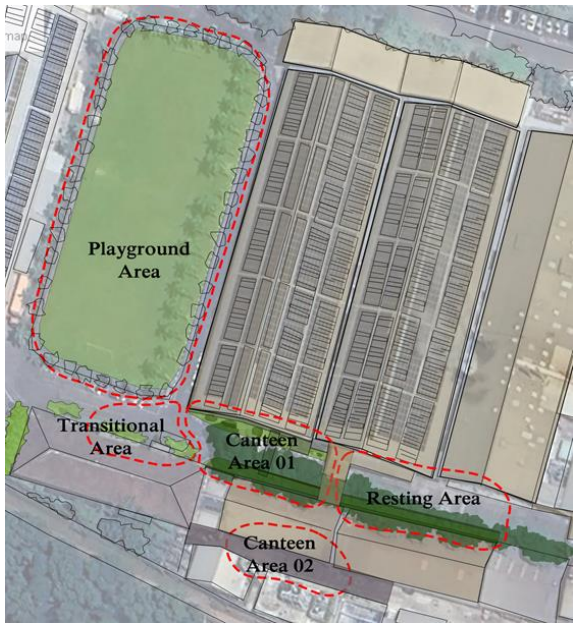


Figure 3 : Sub-divided green industrial landscape spaces (*Source: Compiled by Author*)

According to the workers' needs and their break times, the usage of each space is changing, based on those measurements recorded in that time period. Canteen Area 1, Canteen Area 2 and Resting Space are used in all three break times. But Playground and the Transitional area is specially used only after the 4.00p.m - 4.30p.m. The data is collected in that time periods.

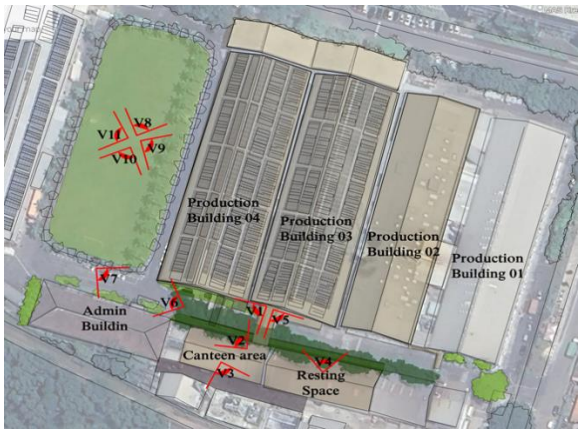


Figure 4 : View Analysis (*Source: Compiled by Author*)

Table 3: Vertical Eye Illuminance Level in Canteen area 01

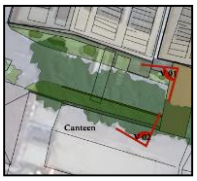
Space and views	Views	8.00 - 8.30	12.30 - 1.30	4.00 - 4.30
	View 01			
		704 lux	* 1390lux	761lux
	View 02			
		364lux	* 951lux	385lux

Table 4: Vertical Eye Illuminance Level in Canteen area 02

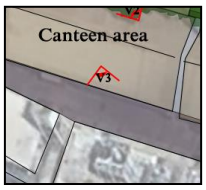
Space and views	Views	8.00 - 8.30	12.30 - 1.30	4.00 - 4.30
	View 03			
		476 lux	* 1432 lux	488 lux

Table 5: Vertical Eye Illuminance Level in Resting Space

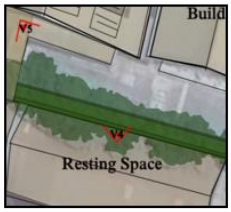
Space and views	Views	8.00 - 8.30	12.30 - 1.30	4.00 - 4.30
	View 04			
		484 lux	* 981 lux	476 lux
	View 05			
		736 lux	* 1230 lux	710 lux

Table 6: Vertical Eye Illuminance Level in Transitional Area

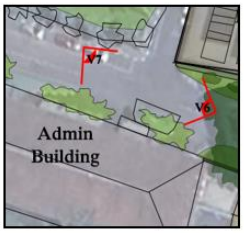
Space and views	Views	4.00 - 4.30
	View 06	
		* 1080 lux
	View 07	
		*1058 lux

Table 7: Vertical Eye Illuminance Level in Playground Area

Space and views	Views	4.00-4.30
	View 08	 * 1252 lux
	View 09	 * 1221 lux
	View 10	 * 1264 lux
	View 11	 * 1215 lux

Table 8: Vertical Eye Illuminance Thresholds (*Source: Suk, 2018)*

Vertical Eye Illuminance	Visual Comfort Level
< 1250 Lux	Comfortable
> 1250 Lux	Discomfort
Up To 3000 Lux	Highly Discomfort

4.1 OVERALL COMPARISON ACROSS ALL SPACES

According to '2.8.1 Vertical Eye Illuminance', the vertical eye illuminance level is defined as the total amount of light falling on the human eye from all visible directions. This means it can vary from space to space depending on the workers' direction of gaze, sunlight exposure, sky conditions, and surface reflections.

The above Figure 5, summarizes how the vertical eye illuminance level has changed at each effective viewpoint. View 03 in Canteen area 02 reports the highest discomfort level, which might be due to the highest luminance level, as shown in Table 4.

Views 08 and 10 in the Playground area also show a slight discomfort, with illuminance values of 1252 lux and 1264 lux respectively. This might be due to direct sunlight exposure and material reflections. In contrast, Views 02 and 04 in Canteen area 01 and the Resting space can be identified as the most comfortable spaces.

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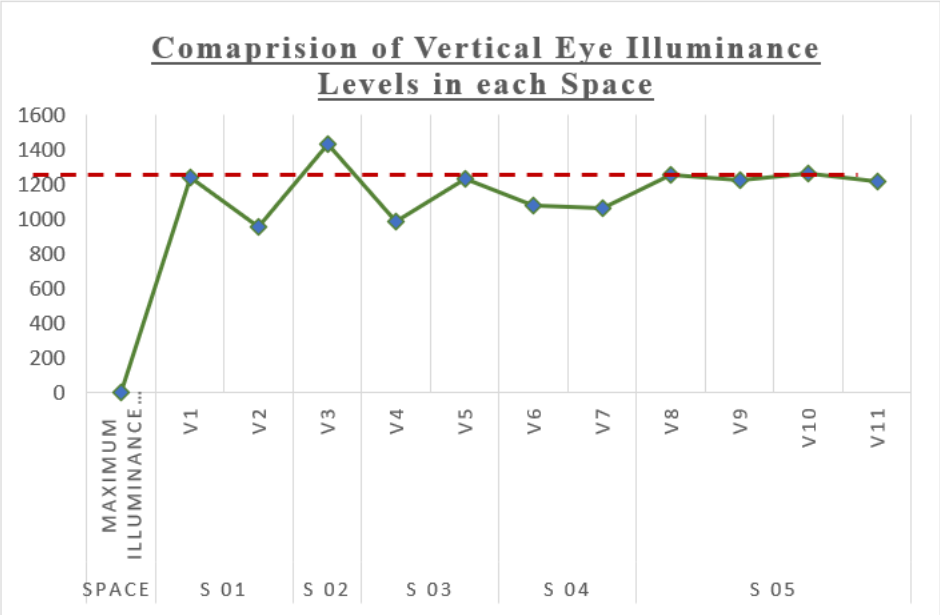

Figure 5: Comparison of Vertical Eye Illuminance Level for all Viewpoints
Comfortable Threshold (<1250 lux)

4.2 FINDINGS

The analysis of the selected green industrial landscape spaces reveals several significant insights into how vertical eye illuminance varies spatially and temporally, and how these variations influence workers' visual comfort within the textile factory environment. Through a combination of on-site lux measurements, behavioural observations, and view-based spatial assessments, the study identifies clear patterns that address all three research objectives.

The first major finding relates to the considerable variation in vertical eye illuminance between different outdoor spaces. The measured data show that areas such as the Playground and Transitional Space consistently record the highest illuminance values, often exceeding the 1250 lux discomfort threshold proposed by Suk (2018). This condition is primarily due to direct sunlight exposure, minimal shading elements, and higher surface reflectance. In contrast, spaces such as Canteen Area 01 and the Resting Seating Space exhibit significantly lower illuminance levels, remaining mostly within the comfortable range across the day. These spaces feature vegetation cover, built shading structures, and favourable orientations that limit direct solar penetration. These spatial differences confirm that the configuration, materiality, and shading quality of green industrial landscape spaces strongly influence the amount of light reaching workers' eyes.

The second key finding concerns the temporal variation of vertical eye illuminance. Measurements collected during the three primary worker break periods (morning, afternoon and evening) demonstrate that illuminance levels fluctuate sharply over time. Midday readings (12.30–1.30 p.m.) consistently produced the highest illuminance values in almost all spaces, with some locations, such as View 03 in Canteen Area 02, reaching more than 1400 lux. Morning and late-afternoon measurements showed comparatively moderate values, except in spaces aligning directly with the sun's position or lacking adequate shading. These results underscore the extent to which workers' visual comfort is dependent on time of day, particularly within tropical climates where sunlight intensity changes rapidly.

The final finding directly addresses the relationship between vertical eye illuminance and workers' perceived visual comfort. By comparing measured illuminance values with the comfort thresholds, the study identifies clear connections between lighting conditions and comfort levels. Spaces recording illuminance below 1250 lux were consistently perceived as visually comfortable, while areas exceeding this threshold caused discomfort due to glare, excessive brightness, or uneven light distribution. Discomfort was especially pronounced in the Playground and Transitional Zones, where direct solar exposure is unavoidable during afternoon break periods. Conversely, the most comfortable spaces particularly within Canteen Area 01 and the Resting Space demonstrated that shaded, vegetated, and visually enclosed environments can significantly reduce glare and improve ocular relaxation.

Taken together, these findings clearly demonstrate that vertical eye illuminance varies according to spatial characteristics, time of day, and viewing direction, and that these variations meaningfully shape workers' outdoor visual comfort in green industrial settings. The results validate that strategic landscape design has a measurable impact on improving lighting quality and ensuring worker well-being in industrial environments.

5. Conclusion

This research set out to investigate how vertical eye illuminance influences workers' visual comfort in the green industrial landscape spaces of a textile factory in Sri Lanka. By integrating quantitative lux measurements with spatial observation and behavioral mapping, the study uncovers critical insights that respond directly to the research objectives and research question.

The findings confirm that vertical eye illuminance is a decisive factor affecting how workers experience outdoor industrial landscapes. Different spaces within the factory environment reveal substantial variations in illuminance due to differences in shading, vegetation density, material reflectance, and viewing orientation. Areas with higher exposure to direct sunlight and reflective surfaces produced discomfort, while shaded spaces with vegetation coverage offered more visually comfortable environments. This highlights the importance of considering landscape configuration and materiality when designing worker-centred industrial outdoor spaces.

Temporal variations further demonstrate that workers' visual comfort is not static but fluctuates significantly throughout the day. Midday periods consistently generated the highest illuminance levels, often exceeding the discomfort threshold. This pattern is particularly relevant to tropical climates such as Sri Lanka's, where intense sunlight can compromise the usability and comfort of outdoor break spaces. As workers typically spend their limited rest periods within fixed times, inadequate lighting conditions during these windows can negatively impact their relaxation, safety, and overall well-being.

The study also confirms a clear and direct relationship between vertical eye illuminance and workers' comfort levels. Spaces with excessive illuminance consistently aligned with reported visual discomfort, whereas spaces maintaining moderate levels supported relaxation and functional clarity. This connection emphasizes that lighting conditions, specifically the amount of light entering the eye play a crucial role in shaping outdoor workplace comfort, even in environments that are designed to be "green" or sustainable.

Overall, the research establishes that the effectiveness of green industrial landscape spaces depends not only on ecological or aesthetic considerations but also on how lighting conditions are managed. The results underscore the need for industrial designers, landscape architects, and facility managers to integrate shading structures, vegetation strategies, orientation planning, and material selection to regulate vertical eye illuminance. By doing so, green industrial landscapes can better support worker welfare, enhance visual comfort, and strengthen the overall productivity and sustainability goals of the textile industry in Sri Lanka.

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