International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 22s,2025
https://theaspd.com/index.php

Quantifying And Analysing Discomfort Glare In Subterranean Learning Environments Using Commercial Lighting Simulation Software

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Abstract
This paper uses commercial lighting simulation software to estimate the Unified Glare Rating (UGR) CIE for discomfort glare. Workplaces, such as workstations, office cabins, classrooms/study rooms, and laboratories located underground, are evaluated for UGR. One of the most frequently cited drawbacks of subterranean space is the absence of natural light. Even if a facility has a relatively low ratio of natural light to artificial light for work tasks, occupiers and users nevertheless value having access to natural light. The sensation that daylight creates, its fluctuation, and the sense of being in touch with the outside world are all significant factors in its appeal, in addition to the discomfort with this kind of construction.
The illumination distributions of solid-state lighting (SSL) luminaires are evaluated and modelled in three dimensions using software, all while accounting for the observer's actual position and line of sight. The luminaire source's luminance and the angle between a luminaire's orientation and the observer's position's line of sight are the primary factors contributing to discomfort glare. The field of view for the UGR values was determined by modifying the values of the three input variables, which is the main emphasis of this paper. UGR readings fall between 10 and 30, with lower being preferable; 16 being perceptible and 19 being only passably comfortable; and more than 19 being more uncomfortable.
This study mainly focuses on quantifying and analysing Discomfort Glare in subterranean educational premises like the computer and electronics lab using Commercial Lighting Simulation Software. This study emphasizes the UGR values, which were determined by changing the values of the three input variables: field of view for the backdrop brightness (Lb), luminance of each luminaire's luminous portions (L), and position index (ρ). The impact of the luminaires' light distribution, the observer's viewing angle and line of sight orientation, and the background luminance effects on the UGR values and conclusion has been studied.
Keywords: *Discomfort Glare; Field of view; Lighting Simulation Software, UGR, Subterranean*

1 INTRODUCTION

1.1 CIE, Unified Glare Rating (UGR):

"The Unified Glare Rating (UGR) is an international index presented by the CIE that quantifies discomfort glare and has become of recent importance." [1] This UGR model was developed by the CIE especially for applications involving interior lighting. The brightness of a fixture for a specific line of sight direction is measured to calculate UGR. In addition to causing discomfort, glare has a number of negative consequences on occupants, including headaches, diminished productivity, and difficulty concentrating.

$$\text{UGR} = 8\,log\left[\frac{0.25}{Lb}\sum\left(\frac{L^2\omega}{\rho^2}\right)\right] \qquad (1)$$

where L is each luminaire's brightness in cd/m^2 toward the observer's eye. ρ is the Guth position index, and ω is the solid angle (steradian) of the luminous sections of each luminaire at the observer's eye. Two angles are used to calculate this index: Lb, or background luminance, and β, or the angle between the line of sight and the line that connects the observer to the source, and α, or the angle, expressed in degrees, from the vertical of the line of sight and the source plane. The background luminance (Lb) is the uniform brightness of the entire surrounding region that, when the glare sources are removed from the visual field under consideration, generates the same illuminance on a vertical plane at the observer's eye (Eq. (2)).

$$Lb = Ei / \pi \qquad (2)$$

Ei: Indirect illumination in the direction of the observer's eyes (lx).
The position index table will calculate the Guth position index ρ, which is the ratio of H/R to T/R produced in Figure 2.

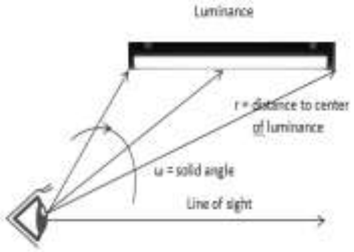

Figure. 1. UGR measurement observer of the observer position

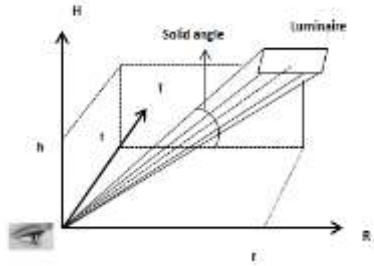

Figure 2. Position of luminaire at the origin eye level

Necessity of Discomfort Glare Analysis Study:
A major problem in visual ergonomics, discomfort glare has an impact on people's safety, productivity, and general well-being in a variety of settings, such as offices, transit, and cities. Even after much research, discomfort glare is still a complicated phenomenon that depends on several variables, including contrast, light intensity, degree of adaptation, and individual perceptual variations. For some reasons, a focused investigation into discomfort glare analysis is required.
Effects on Productivity and Health: Long-term exposure to uncomfortable glare can impair quality of life and productivity at work by causing headaches, visual tiredness, and decreased attention. Inadequate glare management can cause more discomfort and impair cognitive function in settings including businesses, schools, and hospitals.
Safety Issues: Glare can temporarily blind people in transportation situations (such as nighttime driving, flying, and sea navigation), which raises the danger of accidents. In metropolitan areas, glare from artificial lighting or shiny surfaces can reduce vision for drivers and pedestrians, creating dangerous circumstances.

2 Experimentation:

DIAL created DIALux, a free program for designing a workspace's expert lighting. This software is used by many architects and building designers to plan a building's artificial lighting before it is constructed. DIALux calculates the luminance distribution or illuminance of artificial lighting in any given workstation. Additionally, it computes UGR at any line of sight and at any point of view with an angle within 360°. DIALux computes UGR using an equation that uses the simulation's backdrop luminance and the luminances of the light sources, which are derived from the luminaire's luminous intensity distribution.
The CIE UGR method is used in this experiment to assess and analyze the uncomfortable glare while taking into account the workspace, such as an office cabin or study room. DIALux is a lighting simulation program used to simulate a workplace. The simulation's goals are to reach the lux levels that are advised for a certain work. The department's computer lab and electronics lab were the two workspaces for which the simulation was run. DIALux commercial lighting.

DIALux Software Specifications:
DIALux is professional lighting design software widely used for indoor and outdoor lighting simulations, glare assessment, and energy efficiency analysis. It allows architects, lighting designers, and engineers to create realistic lighting models. Below are its key specifications: Lighting Simulation: Artificial & daylight calculations, 3D rendering, Glare Analysis: UGR, DGP, DGI calculations, Standards Compliance: EN 12464-1/2, ISO 8995, CIE 117, CAD and BIM Support: Imports DWG, DXF, IFC; exports CAD formats, Smart Lighting: Sensor-based & dynamic lighting control, Reports and Documentation: Professional lighting plans and energy analysis

2.1 Construction of workplace in DIALux as per specifications

Analysis and evaluation of UGR based on the field of view. Overview of the simulation: The workspace was produced by using commercial lighting software and adhering to specifications. Specifications of the Electronics and Computer lab, located subterranean and DIALux settings are given below

I. Electronics Lab

- Overview of simulation - The workplace created from the following specification
- Workspaces under experimentation: Electronics Analogue Lab, which was placed underground
- Commercial Lighting Simulation Software: DIALux evo 9.2
- Actual Room Size (Meters): 10m × 5.8 m× 3m (L×W×H), Area = L×W = 58m2
- Lighting systems: General lighting system (ceiling-mounted direct lighting fixtures)
- DIALux General setting: Uniformity = 0.5, Maintenance Value (MF) = 0.80, Longitude, Latitude and North alignment setting, and XYZ co-ordinates setting.
- Recommended Values (EN12464-1 Indoor Environment): Lux values = 300lx, UGR<19 (Just acceptable)

As per the specifications, the laboratory is constructed in the simulation software. The luminaire fixtures' positions are fixed as per the actual workplace, as shown in the following figures

Figure 3. Actual workplace

Figure 4. Luminaire fixture position as per the actual workplace

Figure 5. 3D view of workplace in DIALux

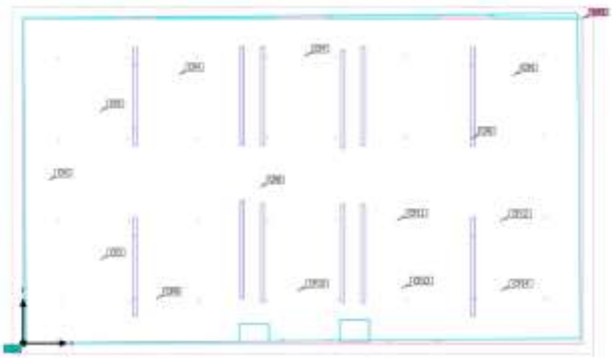

Figure 6. Luminaire position and calculation points in DIALux

II] Computer Lab:

- Overview of simulation - The workplace created from the following specification
- Workspaces under experimentation: Computer lab, which was placed underground
- Commercial Lighting Simulation Software: DIALux evo 9.2
- Actual Room Size (Meters): 8m × 4m× 3m (L×W×H), Area = L×W = 32m2
- Lighting systems: General lighting system (ceiling-mounted direct lighting fixtures)
- DIALux General setting: Uniformity = 0.5, Maintenance Value (MF) = 0.80, Longitude, Latitude and North alignment setting, and XYZ co-ordinates setting.
- Recommended Values (EN12464-1 Indoor Environment): Lux values = 400lx, UGR<19 (Just acceptable)

Figure 7. Computer Lab Workplace

Figure 8. Luminaire fixture position

Figure 9. 3D view of workplace in DIALux

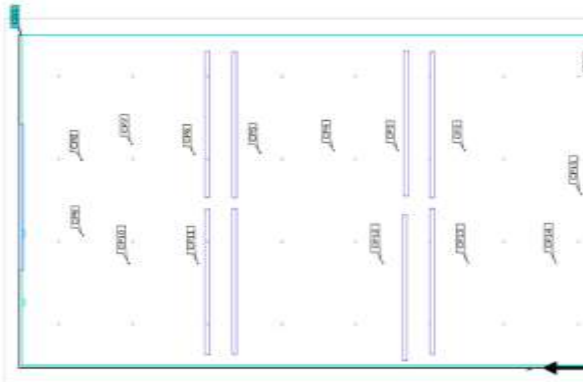

Figure 10. Luminaire position and UGR calculation points in DIALux

2.2 Luminaire information:

Lighting fixtures known as LED batten lights provide consistent, spotless illumination in various spaces. Their energy efficiency makes them extremely valuable. When compared to T5 fluorescent tubes, LED batten lighting fixtures can help consumers save up to 40% on energy costs. There are indoor and weatherproof variants of these lighting fixtures. They can be used to provide linear lighting when combined with LED tubes. According to the room's measurements and the necessary lux level of 300 lx, luminaire flux level of 1900 lm/20W, and luminous efficacy of 95 lm/w, a CRI value of 84 and a CCT of 4000K are chosen for the calorimetric data.

The batten light's package for the color of light, which is determined by its Kelvin temperature. Warm-colored light is produced by those with lower Kelvin temperatures. The higher the Kelvin of the light generated by batten lighting, the bluer it is. The Kelvin scales for white and blue batten lights are 3500–4100K and 5000–6500K,, whereas yellow batten lights have a Kelvin scale between 2700-3000K.Every batten light has a CRI rating. The term "color rendering index" describes how well a lighting fixture can distinguish between different colors. Therefore, choose a batten light with CRI, which indicates the natural color, while making your selection.

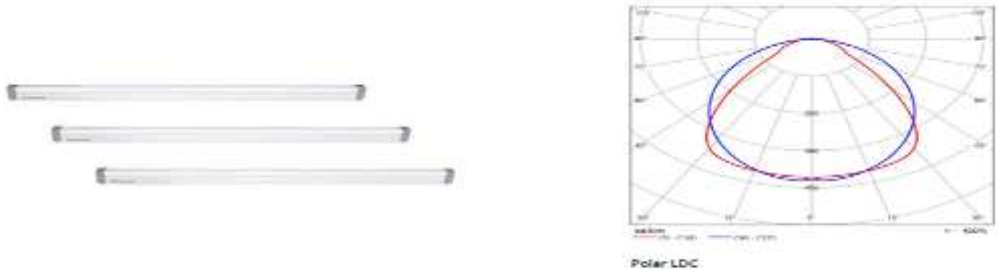

Figure 11. LED batten light Philips BN126C L1900 xLED22S/840 and Polar Intensity Diagram

In the Electronics lab, there are 12 fixtures placed. For UGR surface calculation 4 × 8 (32 points) points spacing by 0.750m on the X-axis and 0.750m the axis facing the north wall at a height of 1.2 meters, and 14 calculation points are placed at the sitting position as shown in the following figure

3. METHODOLOGY:

For office, commercial, and industrial lighting designs in particular, the Unified Glare Rating (UGR) is a commonly used statistic to evaluate how uncomfortable glare is in interior areas. DIALux makes it possible to perform accurate UGR calculations using standardized techniques. A methodical approach to assessing UGR with DIALux evo is shown below.

Outlining the interior space

Geometry of the Room: Establish the room's measurements, taking into account the furniture placement, wall reflectance, and ceiling height. Reflectance and Surface Materials: To guarantee precise light distribution estimates, assign the proper reflectance values to the walls, ceilings, floors, and work surfaces.

Choosing and setting up luminaires

Lighting Fixture Selection: To guarantee realistic photometric attributes, import actual luminaires from manufacturer databases (LDT/IES files).Placement Method: To satisfy task-specific needs, arrange luminaires in accordance with lighting design standards (EN 12464-1, ISO 8995).

DIALux calculation's UGR Calculation Settings Grid Positioning:

Position a UGR computation grid at the occupants' eye level, which is normally between 1.2 and 1.5 meters for seated people and between 1.6 and 1.8 meters for standing people. Establish observation spots according to workstations or standard viewing angles. Choosing an Evaluation Mode: Utilize the UGR calculation tool from DIALux evo, which adheres to the CIE 117 and EN 12464-1 standards. Make sure calculations account for reflections and direct glare.

Using DIALux to perform UGR calculations

Use precise luminance mapping and ray tracing to carry out the lighting simulation. Calculate the UGR values for various observer positions and viewing directions. Compare the outcomes to the suggested UGR limits:

Comfortable (control rooms, high-precision work, etc.) is UGR < 16.

UGR 16–19: Acceptable (e.g., classrooms, ordinary office work).

UGR 19–22: Some unease (e.g., reception areas, industrial zones).

UGR 22–25: Notable discomfort (e.g., factory illumination, retail settings).

UGR > 25: Extremely uncomfortable (e.g., unsuitable for prolonged indoor work)

Improving visual comfort by optimizing UGR:

Use these tactics if UGR readings are higher than what is considered acceptable:

Adjustments for Luminaire Position: Move fixtures to lessen glare that is directly in line of sight.

Utilizing Anti-Glare Optics and Diffusers: Use indirect illumination methods, baffles, or lenses.

Modify Light Output (Luminance Control): Add dimming controls or lower the luminaire's intensity.

Enhance Surface Reflectance Uniformity: Adjust workstation, wall, or ceiling finishes to provide a balanced luminance contrast.

Report generation and validation export UGR reports:

Create DIALux evo UGR reports that include the findings of glare evaluations for various observer locations. In contrast to the standards, Verify adherence to EN 12464-1 specifications for the particular

indoor use. Final Modifications & Design Improvement: Based on research, optimize lighting configurations and placement.
Using DIALux evo for UGR evaluation provides a data-driven, standardized approach to glare assessment in indoor environments. This methodology ensures that lighting designs optimize visual comfort, workplace efficiency, and regulatory compliance.

Part I. Simulation of Electronic Science lab on DIALux

Glare is measured by the UGR value. The more glare the light source produces, the higher the value. The standard height of the UGR observer is 1.2 meters. When α is the angle to the x-axis, its viewing direction is in DIALux (cos(α), sin(α), 0). The red color direction shows the strongest glare at the viewing angle.

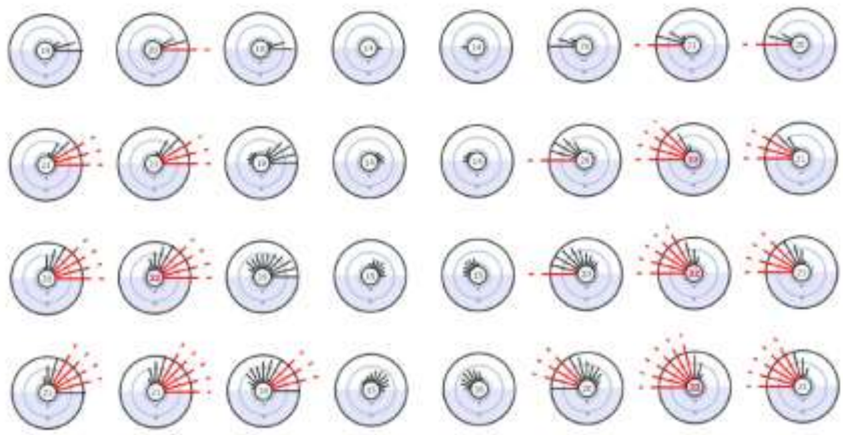

Figure 12. UGR values on the calculation surface

Table 1: UGR values on the calculation surface tabular form

UGR		C1	C2	C3	C4	C5	C6	C7	C8
	Distance (m)	0.6	1.9	3.1	4.5	5.8	7.1	8.4	9.7
R1	5.2	19	20	18	14	14	19	21	20
R2	3.7	21	21	19	14	14	20	22	21
R3	2.2	20	22	19	15	15	20	22	21
R4	0.7	21	21	20	15	16	20	22	21

Human eye level or line of sight is taken into consideration while placing the 14 calculation points in relation to seating positions or workspaces. Height 1.200 m, Step width 15°, Viewing sector 0° to 180°, and Target ≤19.0 for Electronics Lab.

Table 2: UGR Calculation points on the calculation surface tabular form

Calculation point Viewing sector:0 to 180 Step width: 15	UGR	Strongest glare at (in degrees)	Lux levels(lx)
UGR1	21	0	223
UGR2	22	0	452
UGR3	22	15	462
UGR4	19	0	451
UGR5	22	180	241
UGR6	22	180	316
UGR7	10	180	217
UGR8	15	60	252
UGR9	21	30	477
UGR10	12	120	77
UGR11	19	180	249
UGR12	22	180	262

UGR13	20	150	240
UGR14	23	150	268

False Color Rendering of Electronics Lab

Evaluation of rendered spaces is aided by grayscale and false color, or pseudo-color, representations. By portraying them in various hues or grayscale tones and progressing them on an illuminance or luminance scale, these representations provide a brief overview of the lighting distribution throughout the room. This picture displays an isoline diagram of a room with electric lighting overlaid with a false color depiction for illumination.

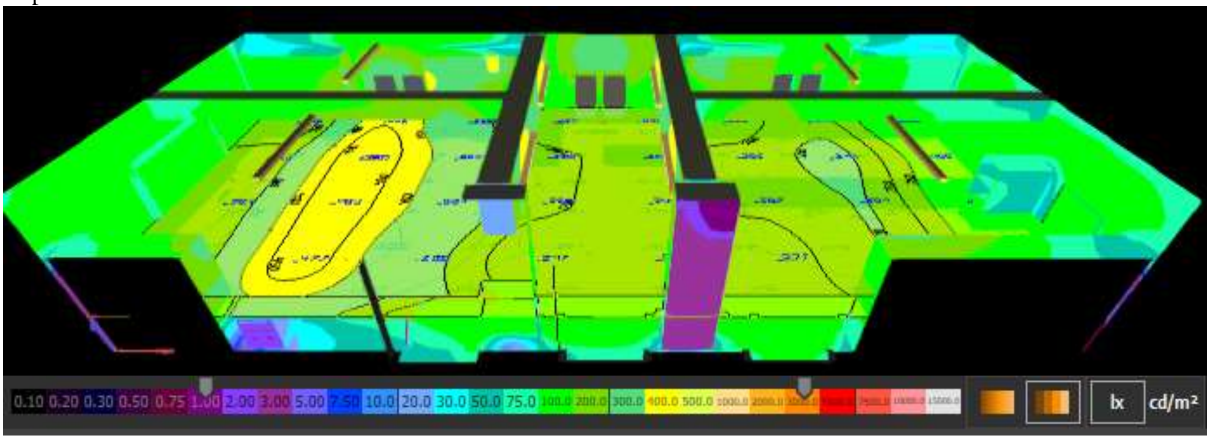

Figure 13. False colour rendering

Part II. Simulation of the Computer Science lab on DIALux

In the Computer lab, there are 12 fixtures placed. For UGR surface calculation, 8 × 4 (32 points) points spacing by 0.750m on the X-axis and 0.750m Y-axis at 1.2 m height, facing the north wall, and 14 calculation points are placed at the sitting position as shown in the following figure

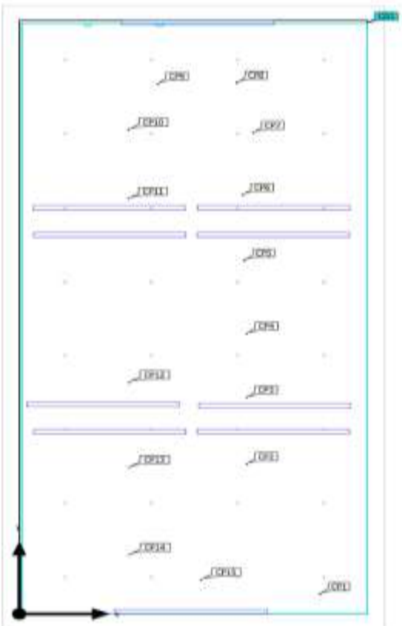

Figure 14. Luminaire fixture positions, UGR calculations point (CP) and calculations surface (8 × 4)

Figure 15. UGR Surface values

Table 3: UGR surface values as per the distance

		C1	C2	C3	C4
	Distance	0.4	1.5	1.5	3.7
R1	0.5	20	21	21	21

R2	1.6	19	19	19	18
R3	2.7	18	19	19	18
R4	3.8	17	18	18	17
R5	4.9	17	18	18	17
R6	6	17	18	18	18
R7	7.1	16	16	16	16
R8	8.1	11	10	10	12

UGR Calculation Points:

Human eye level or line of sight is taken into consideration while placing the 14 calculation points in relation to seating positions or work spaces. Height 1.200 m, Step width 15°, Viewing sector 0° to 180°, and Target ≤19.0 for Computer Lab.

Table 4: UGR calculations points

Calculation point Viewing sector:0 to 180 Step width: 15	UGR	Strongest glare at (in degrees)	Lux levels (lx)
UGR1	21	120	303
UGR2	19	105	343
UGR3	18	90	323
UGR4	17	90	320
UGR5	18	105	337
UGR6	18	90	327
UGR7	16	120	318
UGR8	10	180	304
UGR9	10	0	299
UGR10	16	45	321
UGR11	18	60	313
UGR12	18	75	333
UGR13	19	75	336
UGR14	20	75	389
UGR14	21	90	393

False colour rendering of the Computer Lab:

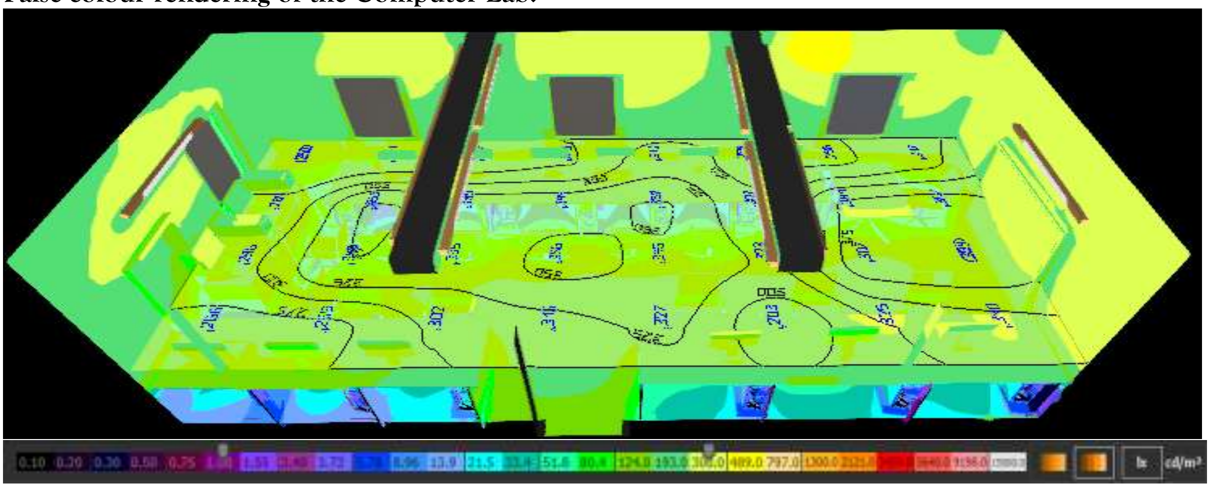

Figure 16. False colour rendering of Computer Lab

RESULT AND ANALYSIS:

I. Electronics Lab:

Figure shows the from right and left side two columns shows the UGR is more than 20 because more luminaire fixture comes in field of view. And the middle columns has UGR is between 14 to 19 that is acceptable because that calculation values are the below the luminaire or above the head.

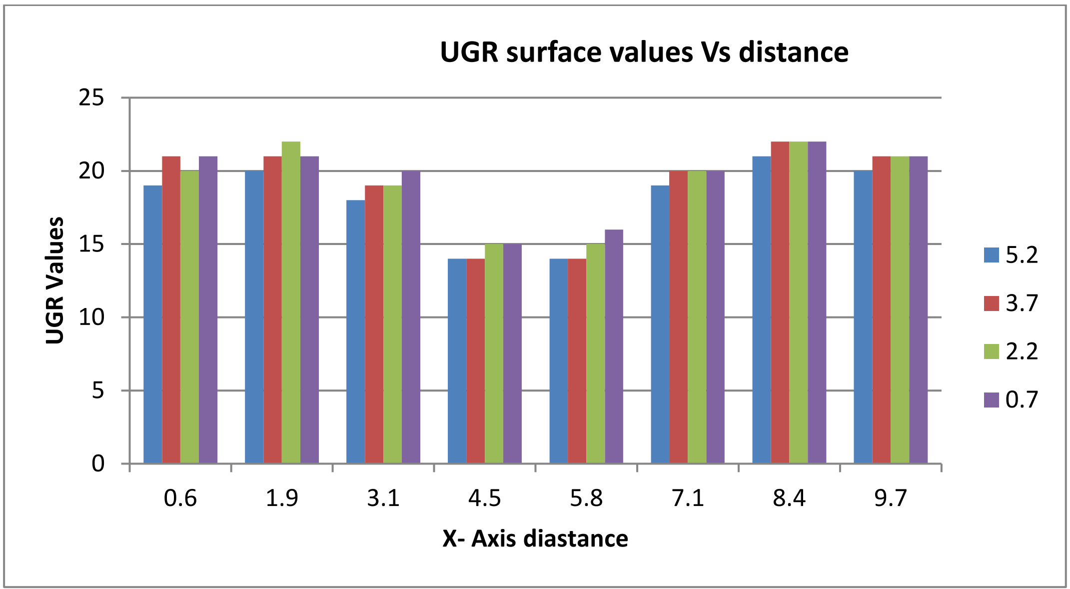

Figure 16. UGR surface values Vs distance for Electronics Lab

II. Computer Lab

The figure shows the UGR from the right and left sides. Two columns show that the UGR is more than 20 because more luminaire fixture comes in the field of view. And the middle columns have UGR between 14 to 19 which is acceptable because the calculation values are below the luminaire or above the head

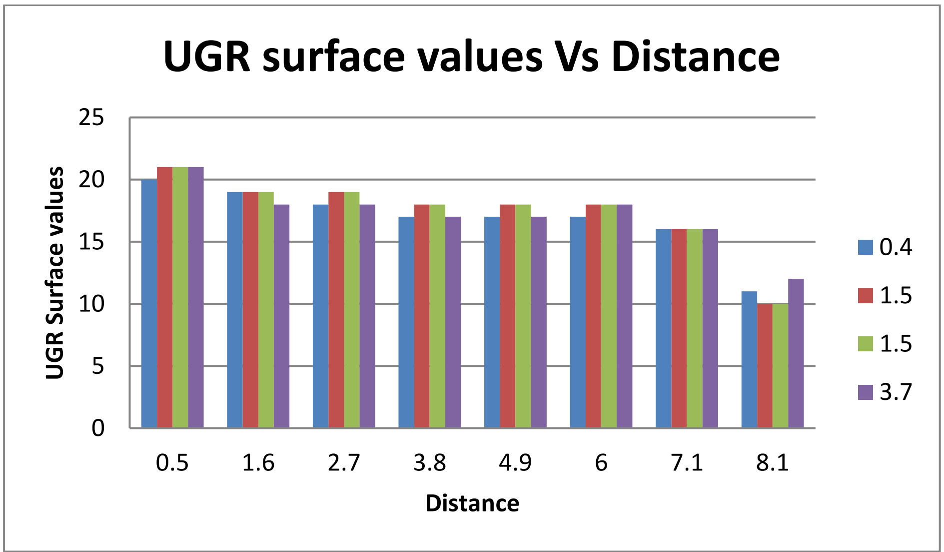

Figure 17. UGR surface values Vs Distance for Computer Lab

4. RESULT AND CONCLUSIONS

Academic Workplaces (Underground)	Dimensions (L×W×H)	Area = L×W	Lumen=lux (300 lx) ×area (lm)	No. of luminaire required =Lumen(lm)/single luminaire(1900 lx)	No.of luminaire actual installed
Electronics Lab	10m×5.8 m×3m	58m^2	17,400	9	12
Computer lab	8m × 4m×3m	32m^2	9600	5	10

According to the calculation, there will be less fixtures than there are now for the task of reading and writing in the laboratory, which requires 300lx. However, due to beams that are part of the workplace's construction, the necessary lux values cannot be obtained. Therefore, more luminaires are needed than are needed, or the luminaire fixtures' orientation and positions can be changed to reduce the number of fixtures and lower the UGR values.

Comfort of Vision (VC) The visual comfort of an inhabited building space is a subjective measure of occupant wellbeing that is impacted by the surrounding visual environment. Natural daylight, light hue, illumination level uniformity, etc. all have an impact on VC. Discomfort brought on by glare, uneven illumination, and low lux levels has an impact on how well students perform in labs or classes. VC in classrooms and labs is linked to symptoms like impaired eyesight, eye discomfort, and frequent migraines. Natural light is scarce in underground workstations. As a result, providing them with adequate lighting is crucial for the tasks they perform. When working in dangerous environments with high temperatures, explosive gases, and combustible dusts, the right lighting solution is crucial.
To assess the amount of glare that users perceive, the majority of the calculation sites are placed in front of the users' positions. Conditions and interpretations of glare. Typically, steps of scales 10–30 are used to determine UGR values. DIN EN 12464-1 states that these phases fall between 10, 13, 16, 19, 22, 25, and 28. The connection between Hopkinson's discomfort glare and UGR value. For instance, if UGR is 18 or 19, the glare is within the "Just Acceptable" (<19) level. The passengers perceive less glare the lower the UGR value. A luminaire with a UGR of 16 will not be as psychologically glaring as one with a UGR of 25. The top limit of UGR for office workplaces, including writing, typing, reading, and data processing, is 19, as per the standards EN 12464-1 (BSI 2011). This also applies to conference and meeting rooms. According to CIE, a location's UGR value of 22 is deemed to be a "acceptable step" in terms of glare requirements if it is higher than the prescribed value.
Future studies should concentrate on the following to improve discomfort glare analysis even more: Integration of Smart Infrastructure with Real-World Applications, putting glare control techniques into practice for better lighting ergonomics in urban settings, workplaces, schools, and hospitals, maximizing glare reduction in transportation and automotive lights to improve pedestrian and driving safety. AI-Powered Lighting Modifications creating machine learning models that use sensor data, user reviews, and current environmental variables to forecast glare discomfort, developing adaptive lighting systems that, in response to human presence and preferences, dynamically modify contrast and brightness to reduce glare. Methods of Dynamic Glare Control, including intelligent shade systems that change on their own according to daylight and glare levels. Using wearable sensors that monitor pupil response and visual perception in conjunction with IoT-enabled lighting to create customized lighting conditions

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