Hybrid lighting approach to improve interior workspace environments: a case study in the UAE

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Abstract

Purpose – Interior workspace environments use exclusively artificial light, resulting in a loss of biological connection and natural light quality, as well as greater energy consumption. The purpose of the study is to identify a suitable system that can provide natural light to such interior spaces throughout the day while supplementing it with artificial light when necessary. The fundamental aim is to provide insights into the most effective solutions for energy-efficient lighting design in the UAE's environment, with the potential to lower energy consumption related to interior lighting.

Design/methodology/approach – The study adopted an empirical approach to gather and analyze primary data based on field measurements to understand and assess existing lighting conditions, as well as DIALux lighting simulation software to test the efficacy of the proposed HLS in terms of natural light delivery, illumination quality and energy consumption. A branch of a local bank in the United Arab Emirates, situated inside one of the shopping malls where there is no natural light penetration, has been chosen as a case study.

Findings – The findings of comparing the base case to four probable scenarios that used HLS revealed that the third scenario, which uses 100% pure sunshine and 35% artificial LED light during daylight operations and 100% LED light during night duty, is considered to be optimal in terms of illumination quality and energy efficiency.

Originality/value – The study demonstrated the potential of innovative lighting to improve the visual working environment in interior spaces with limited access to direct natural lighting, especially in arid regions, where sunlight is plentiful throughout the year. The study contributes new insights into the establishment of lighting-related recommendations and standards for the UAE context. This may include advice for sustainable construction practices, lighting guidelines or incentives to encourage the use of hybrid lighting technology in commercial and institutional buildings.

Keywords Hybrid lighting system, Interior workspace, DIALux software, Illumination quality, UAE, Gulf region

Paper type Case study

1. Introduction

Natural daylight plays a crucial role in our lives, as it helps regulate our circadian rhythms, and has a positive effect on our mental and physical well-being (Karlen *et al.*, 2017). Natural daylight is necessary for the human body due to the interplay of light and dark during the diurnal cycle (Tregenza and Wilson, 2013). Humans need extra illumination to do various

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living chores; artificial lighting types were created mostly in the form of electrically driven lamps, and lights have evidently been widely employed in the built environment. Architects and designers found it easier to adopt a basic single-layer light design at the floor plan level, despite the availability of natural daylight, ignoring its potential in enriching the interior ambiance of building spaces, particularly because it is free, abundant, and inexpensive (Karlen *et al.*, 2017). Several studies were conducted in the early twenty-first century to develop Efficient Daylighting Systems (DLSs) to penetrate windowless zones such as shops and basements (Mayhoub, 2014). Utilizing natural daylight saves energy by reducing dependency on artificial lighting, especially when using lower lux levels (Basurto *et al.*, 2022). Using a control system to arbitrate natural daylighting with artificial lighting has the potential to save more than half of overall lighting use (Basurto *et al.*, 2022). Natural lighting spread evenly throughout the workspaces makes the genuine colours of the items more visible (Winchip, 2022). Lighting technology used to improve building sustainability attempts to prevent wasting unneeded electricity required to uniformly distribute light across a space or to maintain a consistent level of lighting where it is not required (Winchip, 2022). In a 2003 study comparing occupant workspaces with and without access to natural daylight, it was discovered that occupants had superior memory recall and mental function performance, as well as improved overall health conditions (Winchip, 2022). Lighting designers have difficulties when it comes to delivering natural daylight inside building core or windowless spaces (Mayhoub, 2019), which is one of the reasons task lighting is so popular in the workspace. Yet, daylight can be considered task lighting since it allows for the recognition of crucial elements such as colour differentiation (Winchip, 2022). Zeng *et al.* (2022) studied the influence of Correlated Color Temperature (CCT) at the workspace; the experiment found that 4000K was a psychological and physiologically comfortable CCT for participants. The most prevalent light sources for 4000K are fluorescent = 4100K and metal halide = 4000K, both of which define it as a cold colour (Russell, 2008). While light CCT cannot be linked to occupants' emotional responses (Basurto *et al.*, 2022), exposure to extra lights at work may lead to discomfort. The components of a HLS are available on the market, but they are very expensive, making them not particularly cost efficient in certain cases. Yet, the apparent advantages may outweigh the cost. This study investigates how the implementation of HLS may improve visual and workspace environments in the UAE environments. Therefore, the Parans System was chosen for implementation in the case study since it is commercially available in the UAE. Considering the abundance of sunlight throughout the year, natural light is available almost at all hours of the day; however, the prevalence of windowless shopping centers housing a large portion of retail shops makes it extremely difficult to deliver natural light to all of the building spaces. The demand for natural light within the structure necessitates the implementation of novel lighting systems that may be simply installed, efficient, and power-saving. The primary goal of the study is to compare conventional light systems and innovative lighting systems in terms of environmental and energy consumption in order to provide architects and designers with practical guidelines for obtaining the most value from innovative lighting systems that may aid in the initial design stages. Moreover, conducting a case study in the UAE offers a unique viewpoint owing to the region's hot and arid climatic, and architectural characteristics. This setting necessitates customized solutions that take into account high temperatures, bright sunshine, and building design practices characteristic of the UAE.

2. Innovative lighting and visual environment

2.1 Hybrid lighting system

Physiological and psychological studies were carried out to investigate the effect of natural daylight and artificial lighting on the well-being and health of building inhabitants

(Li *et al.*, 2019). Many researchers attempted to find or create methods for improving natural daylight penetration through buildings by utilizing technological innovations while simultaneously reducing reliance on artificial lighting in order to reduce energy consumption and achieve the best Colour Rendering Index (CRI) in the space (Abdelwahab *et al.*, 2023; Karlen *et al.*, 2017). According to Winchip (2022), electrical sources should be seen as a complement to natural sources such as daylight. The proper design of daylight may considerably reduce the quantity of electrical light utilized (Da Silva *et al.*, 2019; Karlen *et al.*, 2017). Referring to the case study of this paper, which is a bank branch considered as a retail business offering financial services to consumers as well as enterprises both large and small, thus it is worth looking at it from a retail real estate point of view, retail is strongly connected with large-scale shopping malls in the UAE (Al Faris and Soto, 2016), where natural daylighting is often unattainable owing to the malls' size and construction. This fact presents a significant problem in terms of sustainability and user comfort; as a result, hybrid lighting technology may give a feasible resolve to these difficulties.

Tubular Daylight Devices (TDDs), also known as solar tunnels, are devices that transport daylighting into a space (Baglivo *et al.*, 2017) and are used in double-loaded corridors, deeply located workspaces, and basements to transfer sunlight from the outdoor environment into the internal environment via diffuse and direct light (Marmoush *et al.*, 2018). Due to weather conditions, TDDs have evolved in various shapes and materials with varied configurations over the past several decades (Baglivo *et al.*, 2017). Another method is the Building Core Sun-lighting System (BCSS), which is designed to distribute sunlight to areas that do not have daylight. This technique uses an exterior solar collector to transfer day light to a distributor device installed within the building to improve interior lighting, but it is still an expensive option (Mayhoub, 2019). According to (Baglivo *et al.*, 2017), the number of TDDs and the length of tunnels provide a particular amount of daylight factor in a space. Moreover (Marmoush *et al.*, 2018), demonstrate optical reflecting tubes that transferred approximately 6.5 W/m2 of outdoor illuminance into required inside space while saving 5.3% of total energy consumption. According to Malet-Damour *et al.* (2016) after combining artificial lights with TDDs, energy consumption decreases and up to 560 Wh is saved at clear sky when the sun is present from 6 a.m. to 7 p.m. Observations also revealed that 60.4% yearly energy savings due to the use of TDDs and LED lighting in the basement parking at Dalian Nationalities University of China. Nevertheless, conserving energy by lowering the usage of artificial lighting would not considerably reduce overall energy consumption due to other building systems that demand a considerable amount of electricity (Li *et al.*, 2019). The optical fiber daylight technology and photovoltaic power generation technology have been developed and begun to be used in a system that blends artificial and natural daylighting in a hybrid solar light illumination system (Lv *et al.*, 2020). The basic technological approach is to install an exterior solar collector that transmits sunlight to a distributor inside the area, together with artificial LED lighting (Mayhoub, 2019). One of the main advantages of hybrid solar light illumination is that it eliminates the infrared and ultraviolet rays that cause skin cancer, since a convex lens installed at the collector side as the daylight entry point to optical fiber creates the light spectrum to be slightly diffused through an effect known as chromatic aberration, and positioning the fiber cable tip at the visible ray at the focal point allows only it to be collected and transmitted ("La Forêt Engineering Co. n.d.", 2022), Light transmitted by fiber optics is equivalent to natural light in terms of Relative Luminosity. Some devices capture sunlight and may combine it with LED light to provide consistent and steady lighting in space (Han *et al.*, 2019). At a workplace, natural light and artificial lighting may work together to provide the appropriate illuminance level for visual comfort, particularly when paired through an automation system that maintains the light lux level within a space (Lv *et al.*, 2020).

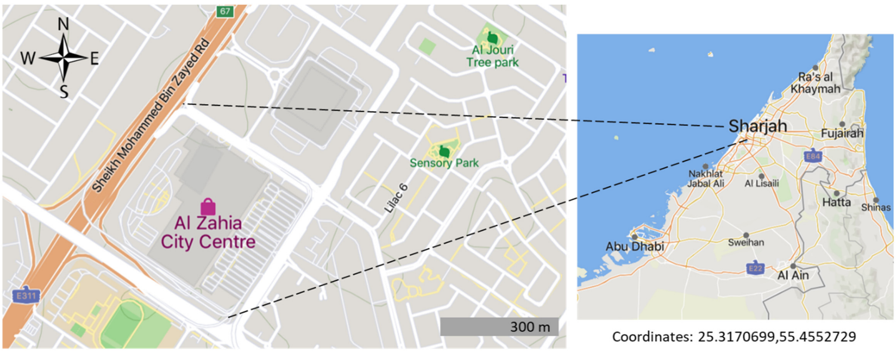
The HLS may be employed in many structures where the core space has little or no access to daylight, such as the basement. The HLS technology, delivers as many lighting spots as required with natural daylight ("Palance - SP4 Solar System", 2020). Moreover, the system is well-known worldwide and has practical applications as a solution to provide natural illumination in confined spaces with solar light. The hybrid lighting is an innovative lighting design approach that combines the best of natural and artificial light sources to produce a more sustainable and efficient lighting system (Mayhoub and Carter, 2011). As more buildings strive to cut energy consumption and enhance the quality of their internal environments, the HLS is set to become a more attractive option for architects and designers. The study aims to interact with the rapid growth of urbanization in the Gulf region, as well as the necessity to identify alternative sustainable solutions, by investigating the adoption of this system as an alternative in order to achieve and improve the workspace environment.

The development and adoption of HLS s is still in its infancy in many countries, including the United Arab Emirates (UAE), where energy prices are still relatively lower in comparison to income levels than in many other parts of the world, in addition to the fact that electrical power is heavily subsidised, but otherwise investment in alternative lighting systems has not been largely accepted. Based on the literature review, there are no studies that specifically look into the application of HLS in the UAE; thus, this study is attempting to take the lead in this area of knowledge by discussing the potential application of HLS in a retail space within a mall, discussing the cost, benefits, and limitations of HLS by comparing real-life data as the base case with simulation to reach the most optimal scenarios. The UAE has launched a strategic initiative to become the first Middle East and North Africa (MENA) Net Zero country by 2050, in line with the Paris Agreement, by developing sustainable strategies to reduce greenhouse gas (GHG) emissions and limit global average temperature rise to 1.5 ℃ above pre-industrial levels. The UAE government will conduct extensive investigations and create strategies to reduce greenhouse gas emissions (GHG) based on sustainability principles (Report, 2023; Zero, 2050, 2021). In line with the country's direction, the renewable energy market will gain traction, increasing the likelihood of the use of sustainable technologies such as HLS; thus, this study is taking the lead in examining the viability of such systems' application, as it is only a matter of time before government policies force the use of alternative methods to reduce energy consumption.

3. Methodology

3.1 Selection of case study

The case study is one of the local banks in Abu Dhabi situated inside the Al Zahia Shopping Mall in the UAE's Emirate of Sharjah (Figure 1). The mall has three floors, making the



Source(s): Mapcarta (2023)

Figure 1.
Al-Zahia City Center geographical location

estimated light travel distance through the fiber optics around 40 meters by passing the conduits through the existing shaft inside the branch all the way to the mall's roof. The site inside the mall has no access to natural daylighting; nonetheless, the UAE has an abundance of daylighting and sunny days throughout the year, with the sun angle ranging from 41° in December to 88° in June. The average percentage of cloud coverage varies greatly by season throughout the year. The brighter days of the year begin in September and last for 7 months, with the cloudier months beginning in March. The shortest day in Sharjah is December 22; the longest day is June 21. The average amount of hours of daylight throughout the course of the year is 12 h and 15 min, which implies that sunshine is available at different levels for half of the day. The mall remains open daily from 10a.m. till 10p.m. as well as the bank.

3.2 Description of interior workspace design

The internal design of selected case study shows the customer area as an open space with customer service desks, tellers, and a waiting room for consumers. The branch manager, cash officer, pantry, and server room all have enclosed areas. The finishes are generally light in colour, accomplished by utilizing white and beige marble, white Corian, and some medium brown wooden elements. The furnishings and fixtures are largely in white, with some cream and grey accents (Figure 2). The ceiling height ranges from 3,80 m to 4,43 m above the finished floor level, and it is built of white painted gypsum board with a drop bulkhead that incorporates a red colour indirect led light for decorative purposes. A recessed spherical spotlight with a diffuser and a temperature of 4000K is used for general illumination. The area has no windows and no other methods of obtaining natural light. The nature of the activities

Figure 2. Inside views of the bank's Al-Zahia Branch

taking place is connected to the processing of banking documents and cash transactions, and all places inside the space are monitored by security cameras. The whole space is entirely dependent on artificial illumination. The luminaires in open spaces are manually controlled. Several drawbacks of current design may be identified, such as the lack of an integrated lighting control system and uneven vertical direction lighting. There are also dark spots on the walls and visible light scallops. During the day, artificial lighting is employed, which causes certain areas to be too illuminated. Employing luminaires with somewhat narrow beam angles in tiny places such as restrooms and pantries.

All enclosed rooms are equipped with presence sensors, while open-air illumination is controlled manually through on/off switches. The primary lighting system is made up of recessed LED down lights, LED cove lights, and recessed LED panels manufactured by Illuxtron International. Table 1 displays the technical details of the luminaires employed, while Figure 3 illustrates the overall illumination distribution in the branch. The emergency lighting system is made up of battery-powered emergency lights that are linked to the Fire Alarm Control Panel (FACP). According to on-site tests, the average light level is 375 lux, which is lower than the usual goal level of 500 lux for a comparable workspace.

3.3 Analysis approach

An empirical approach was used in this study to gather and analyse primary data based on field measurements in order to understand and assess the current lighting conditions in terms of illumination quality and energy usage for the case study. This approach is divided into two phases: the first includes data collected by taking actual site readings/measurements to establish the base case, and the second includes data collected through lighting simulation to evaluate several hybrid lighting scenarios to determine what might be the most feasible strategy for implementing the system in real-life projects in the UAE. Figure 4 illustrates the flow chart of research procedures. Lighting pattern guided integrated design, and the optimal lighting parameters that influence tasks and wellbeing, were measured to assess the base case and all of the proposed HLS scenarios. Table 2 shows the lighting quality criteria that have been chosen in the study.

Criteria	Measurement	Unite of measurement	Target
Illuminance	Average illuminance level	lux	Minimum average of ≥500 lux
Illuminance Variance	Deviation from target illuminance	lux	≥ zero
Lighting Uniformity	Uo = Emin/Eavg	–	0.5–0.6 for workspace
Power Consumption per annum	total system power consumption	kWh/a	Minimum possible
Colour Rendering Index	Average of all luminaires CRI	–	Closest to 1
Correlated Colour Temperature (CCT)	Average of all luminaires CCT	Kelvin	3000–4000
Lighting Power Density	Power/Area	W/m2	Highest possible
Pure Light Utilization	Pure light power	%	Highest possible
Artificial Light Utilization	Artificial light power	%	Lowest possible
Unified Glare Factor	Glare characteristics of the complete lighting system	–	≤19

Table 1.
Lighting quality metrics

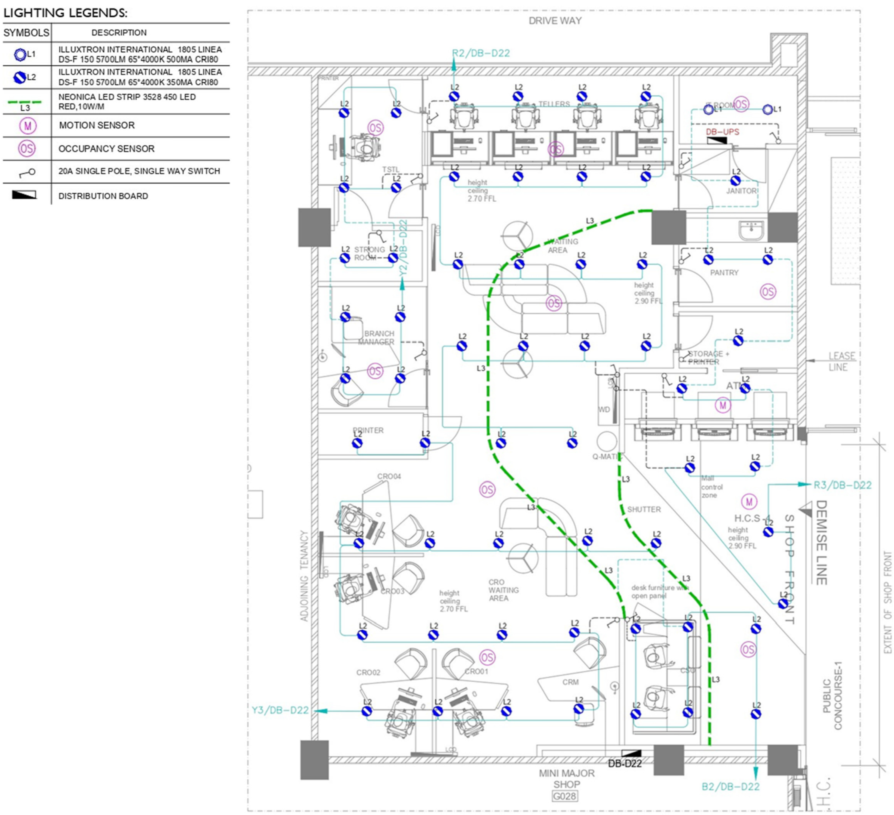


Figure 3.
The overall illumination distribution in the branch

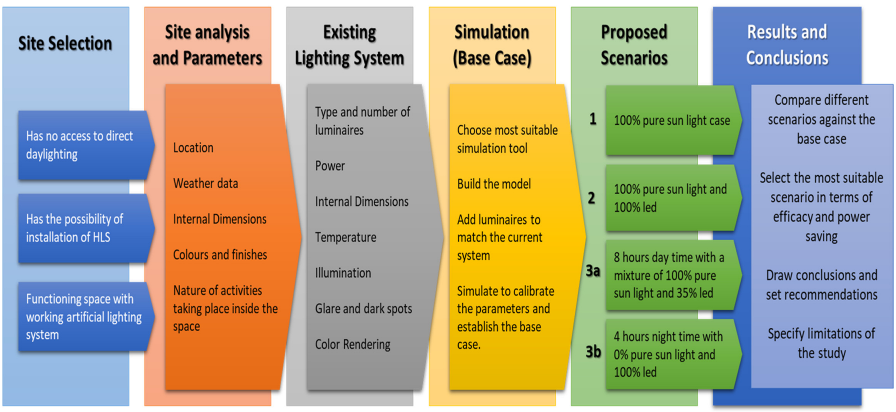


Figure 4.
Flow chart of research procedures

Luminaires	Specification
Down lights Illuxtron International 1805 Linea DS-F 150–5700lm 65°4000k 500ma cri80	- Beam angle (FWHM) 65° - Fixture material Die cast aluminum - Environment Indoor IP rate IP20/IP44 IK rate IK09 - Operating temperature (Ta) −20 °C/+45 °C 1 - Safety marks EN60598/EN62031/EN62471 EMC compliance EN55015 - Colour consistency (SDCM) MacAdam step 3 - Energy efficiency class F (CRI97 3000K)/D (CRI80 3000 K/4000K)
NEONICA LED Strip 3528 600 LED	- LED chip: SMD 3528 - Quantity of LED: 120 pcs/m - Power consumption: 9.6 W/m - Luminous flux: 720 lm/m - Luminous efficiency: 75 lm/W - IP rating: IP 20
Toledo 901700.002 Round recessed downlight	- System power: 16 W - Luminaire efficacy: 113 lm/W - Colour temperature: 4,000 K - Rated luminous flux: 1,800 lm/m - Glare evaluation UGR (4H 8H) 1: 28.6 - Beam angle Down 1: 104°
Robus RU360-01 PIR Occupancy Sensor 360D	- High sensitivity detection diameter 6m. Small movements when working at a desk will activate the sensor - Motion detection diameter 10m. Larger movements such as walking will activate the sensor

Table 2.
Photometric data of the current artificial lighting system

3.4 Modeling and simulation

To show compliance with building codes and design criteria, simulation software has become the primary tool in the fields of environmental sustainability, and lighting design (Azhar and MBC, 2009; Ibarra and Reinhart, 2009). The fundamental reason for utilizing DIALux for lighting simulation and calculations in the study was that it is the primary simulation tool utilized by designers (Bellia *et al.*, 2023), for its fast calculation abilities (Hemmerling *et al.*, 2023), ability to provide a platform to design lighting systems that appeal to users (Guerry *et al.*, 2019), reliable use to test different lighting devices abilities like different lenses used in LED fittings (Kee Xiao Ying and Lim, 2022), and its appeal stems from the fact that it is free, user-friendly, and imports photometric data from about 190 manufacturers ("DIALux", 2023). DIALux can compute the electric light aspects, daylighting, and lighting system power consumptions. It provides values for lighting design performance indicators such as brightness, illuminance, direct daylighting, Unified Glare Rating (UGR), and uniformity, which are the fundamental characteristics for this study.

3.5 Simulation scenarios

The study gathered data through the development of simulated scenarios that represented various hybrid lighting combinations, with the goal of determining the ideal combination and effectiveness of such a system when used in the UAE. The lighting photometrics of the base case model were used for comparison against the simulation scenarios in terms of illumination efficacy and power consumption. Four scenarios have been chosen to be examined against the base case. The first scenario will evaluate pure natural daylight at the workspace to compare daylight performance to lighting quality metrics by considering day light delivered by the system as the sole sources of lighting (PL100%- AL 0%) whereas Pure Light is (PL), and Artificial Light is (AL). The second scenario combines hybrid lighting at 100% capacity during the day with LED as artificial light at 100% capacity (PL 100%- AL 100%), to find out the maximum output of the system. The third scenario (3a) applied 8 h day time with a mixture of 100% pure sun light and 35% led (PL 100%- AL 35%). Finally, the fourth scenario (3b), which could potentially be combined with any scenario to cover the whole bank's working hours (12 h), applied 4 h night time with a mixture of 0% pure sun light and 100% led (PL 0% - AL 100%).

4. Results and discussion

The existing workspace conditions of the bank branch has been implemented in DIALux software by modelling the structure and space finishing materials, and installing 60 LED luminaires in the same fashion as the current artificial lighting system, lluxtron International 1805 LINEA DS-F 150 LED. The software simulation records the LED artificial light at 354 lux, however the real average illuminance level in the present circumstance is 375 lux, with a negligible difference. Despite the fact that the Unified Glare Factor (UGR) is typical and there are no records for unpleasant glare. The results show that the first scenario utilizes 65 sun light luminaires and records a luminance of 265 lux, which is lower than the workspace guideline index and has ununiformed lighting as seen by dark spots on the floor (Figure 5a). However, Parans System relies only on sunlight to illuminate the workstation, implying that this scenario cannot rely solely on sunlight throughout the day, necessitating the installation of LED artificial lighting in the room. The Unified Glare Factor (UGR) was normal as shown in Figure 8a.

The second scenario utilized 100% pure sunlight light and 100% LED light for 8 h. The findings indicate that the intensity of illuminance at the desk reaches 805 lux, which exceeds the previously specified guideline restriction of 500 lux solely for workspace activities (Figure 5b). By installing 60 hybrid lighting outlets luminaires. The outlet combines two types of luminaires: pure sunlight luminaires and LED luminaires as shown in Figure 6. The room has a high light record, with a colour rendering index (CRI) of 087 and a correlated colour temperature (CCT) of 3500 K. However, the Unified Glare Factor (UGR) is small and within acceptable limits in this scenario (Figure 8b).

The third scenario (3a), like the second, utilizes LED artificial lighting. The pure sunlight will be perpetual, as in the previous scenario, and the LED artificial light will only be turned on with a capacity of 35% for 8 h during the bank's business hours, using the same fitting outlet numbers of luminaires as in the first scenario (Figure 7a). Findings show that the illuminance at the desk may reach 512 lux in the range of guideline control for workspace activities, the colour rendering index (CRI) was 0.9, and the correlated colour temperature (CCT) was 3250 K. However, the simulation reveals that the Unified Glare Factor (UGR) is negligible, which is within an acceptable range (Figure 8c). The fourth scenario (3b) encompassed disabling pure sunlight light and enabling 100% LED artificial light for four hours at night. However, the identical fitting luminaire outlet numbers and specifications are employed in the first scenario (Figure 7b). The illuminance records found at the workspace exceed 537 lux. Furthermore, the colour rendering index (CRI) was 0.8, and the correlated colour temperature (CCT) was 4000 K. Despite this, the simulation reveals that the Unified Glare Factor (UGR) is in an acceptable range.

The annual energy consumption decreases considerably in the third scenario, in which the workspace relies solely on natural sunlight for 8 h per day during bank duty hours and is supplemented by 35% LED lighting. The study concludes, based on the above results, that

Figure 5.
A comparison of the basic case simulation results against the first and second scenarios (a) Utilizing solely the HLS (PL100%- AL 0%) (b) Utilizing 100% pure sunlight and 100% LED illumination (PL 100%- AL 100%)

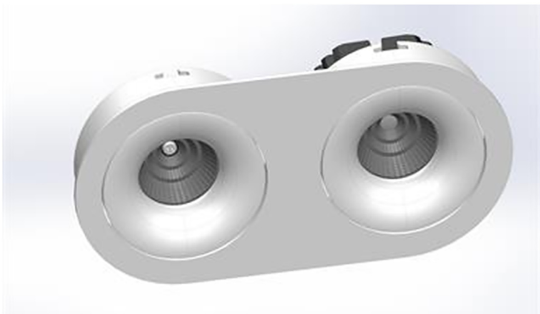


Figure 6.
A typical type of luminaire utilized in the second scenario

(HLS) can reduce illumination power consumption by 74%. The third scenario, which runs from 10 a.m. to 6 p.m., paired with the fourth scenario, which runs from 6 p.m. to 10 p.m., is suggested by the study as the most effective approach to implement HLS. Examining the

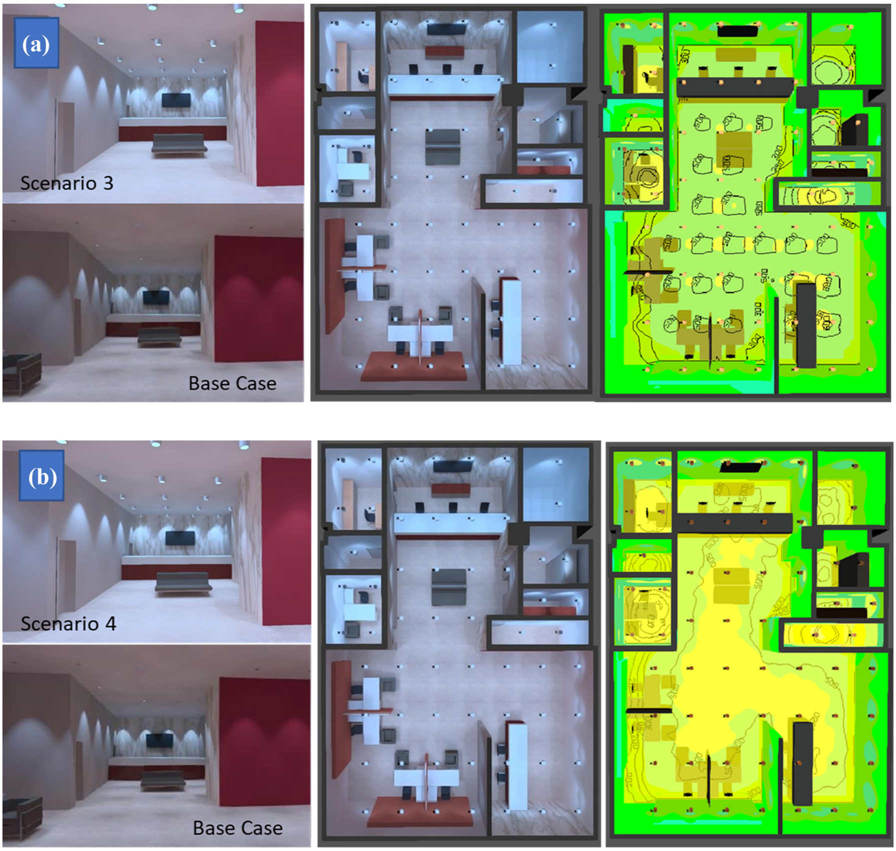


Figure 7.
A comparison of the basic case simulation results against the third scenario (3a) and the fourth scenario (3b) (a) Utilizing 100% pure sunlight light and 35% artificial LED light throughout eight hours of daylight (PL 100%-AL 35%) (b) Utilizing 4 h at night time with 0% pure sun light and 100% LED artificial light (PL 0%-AL 100%)

illumination power density, the study discovered that the power per square meter decreased from 8,1 W/m2 to 5 W/m2. In accordance with article 5.26 of European Standard EN12464-1, the average illumination uniformity for an office ranges from 0.4 to 0.6; the result is 0.57, which is close to the optimal uniformity (Ensto, 2011). Table 3 provides an overview of the most significant findings from the DIALux software simulation regarding the four different scenarios. The study can indicate, based on the aforementioned findings, that the use of HLS will enhance the space's illumination efficacy while reducing energy consumption.

In the UAE setting, it may be difficult to get your hands on accurate statistics on consumption of energy, environmental factors in terms of implementing HLS in buildings. Implementing HLS could lead to substantial upfront expenses for the installation and acquisition of equipment. Insufficient budget allocations or financial resources may limit the extent or magnitude of the study. Moreover, architects and designers concentrate on solving daylighting penetration into buildings using architectural components in order to lower the owners' financial budget. In the current study, only a few international case studies were discovered, and those that were discovered lacked detailed information about the HLS's implementation, making it difficult for the investigator to include data such as power consumption, illumination level, and so on in the review of the international case studies.

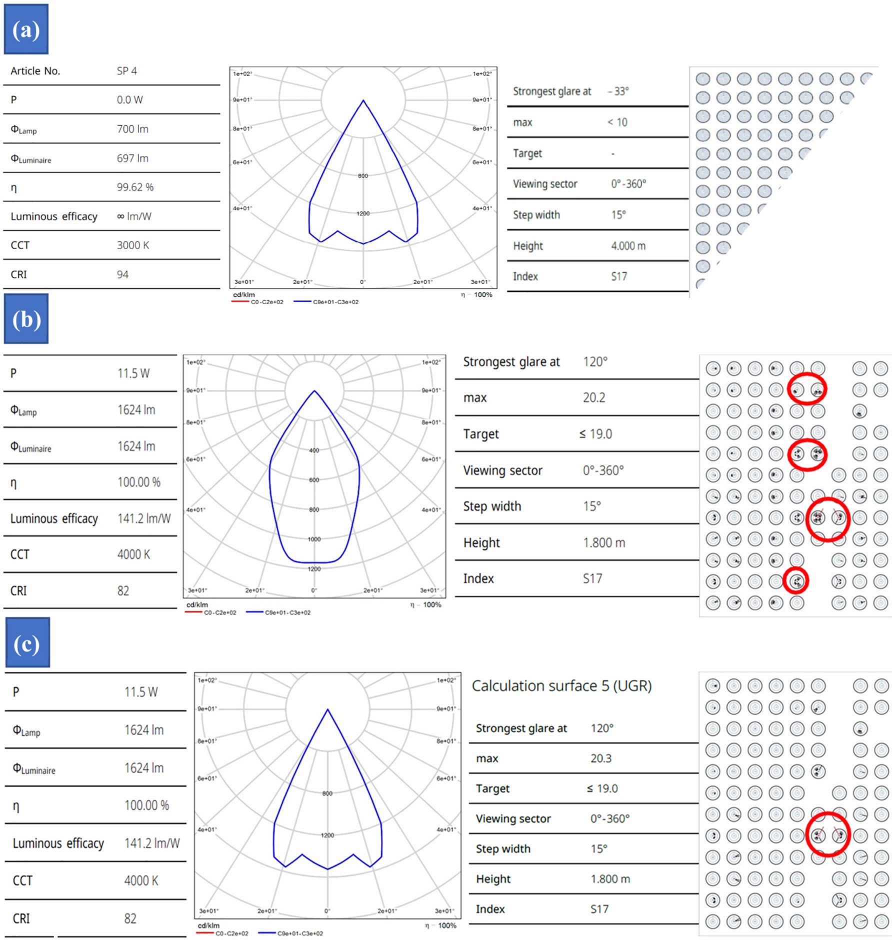


Figure 8.
Luminaire specs and Unified Glare Factor (UGR) for all scenarios (a) The first scenario (b) The second scenario (c) The third scenario

5. Conclusion

The study aimed to examine the applicability and efficacy of HLS in a retail banking space located inside a shopping center in the UAE with no direct access to natural daylighting. The simulation of four different scenarios showed a significant improvement in workspace illumination, colour rendering index, and reduction in power consumption when the system used a mixture of pure natural sunlight throughout the daytime, supplemented with a lesser proportion of artificial light. However, it relied entirely on artificial illumination for a few hours after sunset. The third scenario, which uses 100% pure sunshine and 35% artificial LED light during daylight operations and 100% LED light during night duty, is considered to be optimal in terms of illumination quality and energy efficiency. This conclusion was drawn following comparing the base case against the four possible scenarios that used HLS. The improved lighting quality helps the business functions inside the bank to be carried out more effectively. The study demonstrated the potential of

Criteria	Base Case	Pure Light	HLS 100–100%	HLS 100–35% Day 8 h	HLS 0–100% Night 4 h
Illuminance (Avg.)	354 lux	265 lux*	805 lux	512 lux	537 lux
Illuminance Variance	−146 lux	−235 lux	+305 lux	+12 lux	+37 lux
Avg. Lighting Uniformity	0.6	0.5	0.57	0.56	0.57
Power Consumption per annum (kWh/a)	7117.5	0	3274	763	1091
Power Consumption per annum (USD $)**	783	0	360	84	120
Power Saving Against Base Case (USD $)	–	783	423	699	663
CRI	0.8	0.94	0.87	0.9	0.8
CCT	4000K	5000 K	3500K	3250 K	4000K
Avg. Lighting Power Density	8.1 W/m2	0 W/m2	3.7 W/m2	1.3 W/m2	3.7 W/m2
Pure Light Utilization (12 h)	0%	100%	100%	100%	0%
Artificial Light Utilization (12 h)	100%	0%	100%	35%	100%

Note(s): * The pure light average illuminance data was taken from DIALux software, and considered since sun cast prevails most of the year in the UAE
** The pricing was utilized as a point of reference (Latest news, 2022)

Table 3. An overview of the most significant findings from the DIALux simulation regarding the four different scenarios

innovative lighting to enhance the visual workplace environment in spaces with zero access to direct natural lighting, particularly in an arid climate like the UAE, and the Gulf region, where sunlight is abundant throughout the year. The study contributes novel insights into the development of lighting-related guidelines, and standards tailored to the UAE context. This could involve recommendations for sustainable building practices, lighting codes, regulations, or incentives to promote the adoption of hybrid lighting technologies in commercial and institutional buildings. The limitations of the study include the relatively recent development of the technology, the lack of prior research, and the high upfront cost, which would result in a sluggish return on investment given the UAE's comparatively cheap power pricing. Future research might look into hybrid lighting in additional applications and concentrate on incorporating the system early in the building development process to lower the initial cost.

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