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Technological Systems Used in Integrating Natural and Artificial Lighting in Administrative Buildings to Achieve Global Sustainable Lighting Strategies

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ABSTRACT

This paper displays the sustainable lighting systems used globally in administrative buildings to achieve visual comfort and reduce energy consumption. The main issue lies in the absence of declared sustainable strategies integrating natural and artificial lighting, coupled with a shortage of studies addressing the evolution of these strategies over time. The paper aims to trace the development of sustainable lighting design strategies in administrative buildings to support future research and build a clear framework. This is achieved by presenting a range of techniques and technological systems, including building envelope design systems to enhance natural lighting utilization, light enhancement systems within spaces to increase visual effectiveness, light polarization systems to improve natural light distribution, appropriate artificial lighting systems to effectively meet lighting needs, and lighting unit control systems to reduce energy consumption. The benefits of using these strategies are evaluated through the study of their application in global projects that have received LEED or BREEAM ratings, with the aim of deriving strategies for integrating natural and artificial lighting to achieve sustainable lighting in administrative buildings and guide the design of lighting in future administrative buildings to increase their energy efficiency while ensuring visual comfort.

1. Introduction

Light plays a significant role in human comfort within the work environment. Consequently, previous studies have focused on the proper design and distribution of natural and artificial lighting to achieve comfortable eye lighting and enhance production efficiency. With the increasing issues of energy consumption and global warming, scientists have turned to sustainability principles through the use of technology in building lighting. Administrative buildings, being one of the largest consumers of artificial lighting energy, necessitate the use of modern technologies to reduce energy consumption and provide comfort for employees, while addressing visual problems arising from urban growth and surrounding building heights. This research presents integrated systems of effective lighting solutions tailored to the building's location, economic conditions, and user types. It examines the evolution of lighting technologies used in global administrative buildings and their management, which have significantly contributed to visual comfort and

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building sustainability. Case study projects were selected based on their adherence to architectural principles and receipt of global environmental building ratings such as LEED or BREEAM from 2004 to 2024 with the selection of the most famous buildings of this period, which have all the systems that achieve the required lighting strategies in the building.

1.1. Research problem

The lack of lighting design management in administrative buildings regarding sustainable strategies for natural and artificial lighting leads to a shortage of integrated and effective solutions that suit the building's location, economic conditions, and user needs.

1.2. Research objective

The research aims to study the evolution of lighting technologies used in global administrative buildings and their management in order to Achieve strategies that include an integrated system of effective natural and artificial lighting solutions that align with the building's location and economic conditions, to achieve visual comfort for the space users and building sustainability and to provide recommendations for improving the design of lighting systems in future administrative buildings.

1.3. Research Methodology

The research paper follows a theoretical study, that displays the strategies for designing natural and artificial lighting in administrative buildings, then an analytical study involving the analysis of various global case studies of administrative buildings, and finally a deductive study to derive integrated methodologies and strategies for designing sustainable lighting in administrative buildings in the era of globalization.

2. strategies for designing natural and artificial lighting in administrative buildings

the strategies is a form of various solutions and technological systems used in an integrated form.

2.1 Natural lighting systems

Scientifically, there are various systems that have their influence on enhancing the natural lighting in the building such as the design of the building and its envelope, using advanced glazing systems and the usage of shading systems which contribute to maximizing natural light penetration while maintaining visual comfort. the selection of facade angles, and reflection affect the performance of natural lighting. Integrating innovative solutions such as light polarization systems that enhances natural light levels, especially in densely populated urban areas with high-rise constructions[1] . also there are various systems used in designing the interior space to enhance the natural lighting inside the building. And Light assembling systems used inside or outside the building.

2.1.1 the design of the building and its envelope

Design of buildings plays a crucial role in optimizing natural lighting. four factors concerning the design have their impact on the amount of natural lighting gained by the building envelope, the building shape, concerning the orientation in the design phase, concerning the surrounding reflections and the size of the windows of the envelope. these factors enhance visual comfort and energy efficiency within the space [2] The building envelope is significantly influenced by orientation regarding the amount of solar radiation it receives, which reflects on the total thermal load of the building by utilizing the solar radiation's reflection property at certain angles, regarding that Solar radiation passing through glass remains constant at a 45-degree angle and decreases in reflection at angles beyond 70 degrees. This property helps in avoiding direct solar radiation, especially during midday when the sun's inclination increases, effectively shading the building.[3] Orienting the larger side of the building towards the south is considered the best direction for achieving energy savings of up to 35% in lighting and heating. Given that the highest levels of brightness and illumination are typically on the southern facade, orienting the shorter side towards the east and west and the larger side towards the north and south helps leverage this characteristic. The more sunlight there is, the more light and warmth. It is important to design openings with an appropriate size based on the type of facade and to use shading elements to reduce glare and ensure visual comfort [4] as in fig (1).

Fig 1. The usage of large glass openings on the north facade of the building and Slope in the surface of the atrium

One of the most important factors while designing the envelope of the building is to concern the surrounding environment significantly the impact of the reflected light rays on the building façade through the surroundings. Studies have shown that factors such as the height of surrounding buildings, street width, orientation, and the presence of obstructing structures can reduce average lighting levels by up to 40% in west-facing windows and at least 15% in south-facing windows [5]. Additionally, the reflection of light from external surfaces, the angle between facades, water bodies, and plants around the building, all have an impact to increase the average annual lighting within the space [6] as in fig (2).

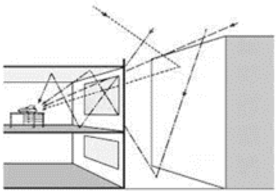


Fig 2. Reflected natural outdoor lighting from the project site onto the building's openings

2.1.2 *Advanced glass systems for sustainable natural lighting*

Advanced glass systems have facilitated the development of strategies to enhance daylight utilization within spaces while ensuring thermal control and glare protection. This includes integrating liquid glass coatings and shading systems within glass layers to maintain consistent daylight levels and improve thermal conditions [7]. The integration of electrochromic glass has demonstrated its significant capability in reducing glare, maximizing useful daylight, and consequently reducing reliance on artificial lighting [8] . Multiple layers of glass and the use of double-glazed facades in building design also contribute to enhancing visual comfort while addressing several environmental concerns such as reducing noise, improving thermal comfort, and enhancing energy efficiency compared to single-glazed facades. [9] fig (3),

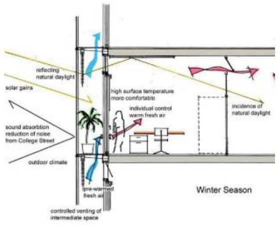


Fig 3. section in the double glass facade.

2.1.3 *Shading systems*

There are various methods of shading used to control the amount of sunlight entering a building, significantly reducing heat gain and improving natural lighting quality in interior spaces. These methods enhance visual comfort by controlling glare and reducing contrast ratios. Shading devices, which can be designed for either the interior or exterior of the building, may use fixed or movable systems with control mechanisms to automatically reduce electric lighting levels.[3] ‹Here are some shading systems for openings:

Louvers: they controlled sunlight penetration through external openings while blocking others based on design needs. They are designed to be vertical or angled to provide shade from direct sunlight and come in various forms, including horizontal, vertical, fixed, or movable configurations.[10]. In fig (4), perforated fibre panels are used as louvres that periodically adjust their position in response to sunlight, providing natural lighting and protection from the sun's rays. [3].

Fig 4. The Kiefer Technic administrative building in Australia shown with all louvres closed and open.

Mashrabiya: An innovative technique in Islamic architecture, shown in fig (5) combines aesthetic design with functional solutions for shading, privacy, and maintaining an exterior view. This system can adjust the size and shape of the openings based on sunlight intensity and external light conditions.[3].

Fig 5. The external envelope of the building - natural lighting inside.

Fabric awnings: They are thin, elastic fabrics capable of stretching and shaping freely, with resistance to air pressure. These fabrics comprise a thin network varying in manufacturing method and weaving across different types. They are double-layered, covering both sides with materials that connect the main fabric layers of the membrane, protecting them from moisture, radiation, fires, fungi, and ensuring their expected lifespan.[11]. In the Seaside Towers building as in fig (6), a secondary facade is employed. This facade can be mechanically opened in response to temperature variations, aiming to reduce glare and enhance comfort levels. [12].

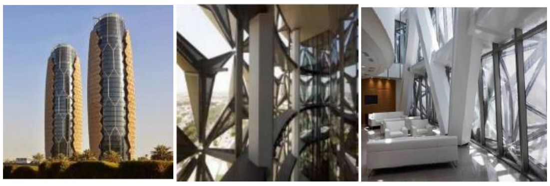


Fig 6. the building envelope from the outside and inside.

plants: Trees reduce direct sunlight entering a building through shading, lowering surface temperature and glare. They also block scattered radiation from the sky and surrounding surfaces, contributing significantly to user comfort. [13]. Deciduous trees can naturally regulate the climate throughout seasons when positioned in front of openings, providing effective climate control [14]. Trees can be integrated into building envelopes, offering new design possibilities and enhancing thermal comfort inside the building[15]. fig (7).

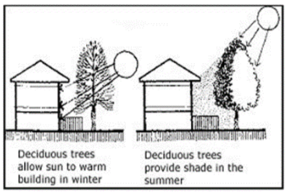


Fig 7. The effect of plants on the penetration of sunlight inside the building.

Curtains: are widely utilized as protective elements in administrative buildings, offering the ability to either reflect or transmit light into the structure. They also provide shading and contribute to an appealing external aesthetic. [12] ‹They reflect some of the radiative heat energy outwards, decreasing solar heat gain by around 60-70%, while also assisting in glare reduction [14]. They can be controlled by sunlight sensor systems. [16] as shown in fig (8).

Fig 8. Double slanted Venetian blinds in white, movable slats.

2.1.4 lighting enhancement systems in the internal spaces of buildings

Fixed and Movable elements: fixed elements such as walls, ceilings, and floors define the interior space of the building, interacting with light as both recipients and influencers. Natural lighting openings are integrated into these elements or artificial lighting units are installed on them, some of which are used to receive light while others are used to reflect it, thus serving as secondary sources of illumination.[17]. It can be used for interior space lighting as an alternative to glass in walls and ceilings, such as using transparent concrete, transparent wood, and polycarbonate panels. These materials are characterized by excellent impact resistance, high optical clarity, and surface resistance to UV rays and scratches. [18] as in fig (9), movable elements are used as modular furnishings and separate or suspended reflectors as a method of light reflection, distribution, and dispersion within the building space[19] .

Figure 9. Polycarbonate sheets used in the sky light of the building.

Lighted shelves: they are innovative daylighting devices that work to enhance the distribution of daylight and reduce glare in buildings. [20] they work to increase the penetration of natural light deeper into the space by redirecting incoming daylight towards the ceiling, thus reducing the need for artificial lighting and consequently decreasing energy consumption.[21] they also help mitigate lighting differences between areas near openings and deeper within the space, thereby enhancing overall lighting uniformity[22] design criteria such as height, width, materials used, shelf angle, and whether the shelves are internal or external impact the performance of lighting shelves, as in fig (10). Additionally, variations in shelf shapes yield different results in the dispersion of natural light within the space[22] .

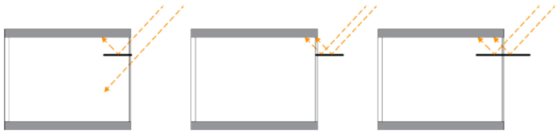


Fig 10. The effect of the light shelf's location on light reflection inside the space.

2.1.5 Light assembling systems (Gathering or collecting light for deep or far spaces)

These systems transfer natural light from the exterior to interior spaces where sunlight is difficult to reach through exterior openings, allowing the benefits of natural light at minimal cost. They can be devices mounted on the building's exterior that use daylight collectors to then transmit it to diffusers in the interior spaces[23] like solar tubes as in fig (11). they can be part of the building's design, like the court and the atrium [24]. Also may include reflective elements to enhance light distribution within it.

Fig 11. A solar tube section inside the building.

2.2 Artificial lighting systems

artificial lighting is used as supplementary lighting when natural light is insufficient during the day. The artificial lighting system offers several options to save energy at a low cost, such as choosing energy-efficient units and controlling them using various methods along with utilizing energy production sources.

2.2.1 Energy efficient lighting units

Energy-efficient lighting units are among the most economical solutions for artificial lighting systems in buildings, providing the necessary light for visual comfort. Among the best types of units used in administrative spaces are LED lamps, known for their energy efficiency, consuming at least 75% less energy than traditional units and lasting 25 times longer than incandescent lighting units. Additionally, they are durable, cool, mercury-free, and cost-effective. LEDs can also be controlled for brightness and color using dimmers.[25] Table (1) shows some characteristics of LED units compared to other types of lighting units.

Table 1. Characteristics of LED lights, incandescent lights, and CFL lights

Feature	Light Emitting Diodes (LEDs)	Incandescent Light Bulbs	Compact Fluorescents (CFLs)
Life Span (Hours)	Typically above 50,000	1,000 – 2,000	8,000 – 10,000
Wattage (equivalent to 60 W Incandescent bulb)	6 – 8 W	60 W	13 – 15 W
Temperature Sensitivity	None	Yes, Somewhat	Yes
Sensitive to humidity	No	Yes, Somewhat	Yes
Switching On/Off Quickly	No Effect	Yes, Somewhat	Yes – lifespan can reduce drastically
Turns on instantly	Yes	Yes	No – takes time to warm up
Durability	Durable – can handle jarring and bumping	Glass or filament are fragile	Glass can break easily
Toxic Mercury	No	No	Yes

artificial lighting units may be used to produce light similar to daylight in spaces that are distant from openings or in areas that lack openings, known as an intelligent artificial lighting system. the design of the SIVRA system shown in fig (12), is a simulation of skylight artificial lighting that mimics daylight to enhance ambient stimulation through continuously varying light in colour and intensity [26]

Fig 12. Using SIVRA artificial lighting varies in color and intensity over time.

2.2.2 systems for producing Renewable energy:

among the various renewable energy sources, photovoltaic solar energy is considered one of the best solutions to reduce the impact of fossil fuels on the environment. fig (13), fig (14) shows photovoltaic cells installed on the exterior of the building. Integrating shading systems with photovoltaic cells to form double-skin facades improves visual comfort while simultaneously generating energy. This presents a unique proposal for fast-responsive facade systems.[27] the use of Building Integrated Photovoltaics (BIPV) is considered a thriving solution towards green, smart, and sustainable buildings. These are techniques that replace traditional building components with components that harness solar energy. Glass openings may be one of these components, where they are replaced with semi-transparent solar cells as in fig (15). Considering the Window-to-Wall Ratio (WWR), the orientation of the building walls, and transparency are essential to achieve the appropriate lighting level inside the space [28].

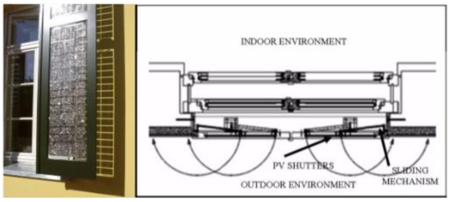


Fig 13. The photovoltaic Louvers installed in the building envelope openings.

Fig 14. The solar panels act as Louvers on the south facade of The Edge building.

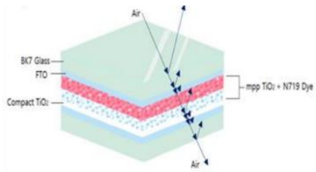
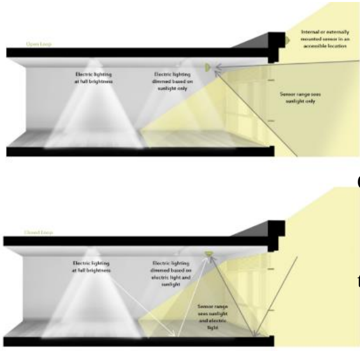


Fig 15. Embedding photovoltaic cells in the glass openings to function as semi-transparent solar cells.

2.2.3 Control systems:

Smart control strategies in daylight and artificial lighting enhance user comfort, a key factor in system efficiency through active user interaction with automated controls. These strategies also meet energy goals by reducing the need for artificial lighting in the building [29]. Control methods should be customized to suit the diverse functions of spaces, spanning from large open offices and conference rooms to corridors and reception areas. [30] as in fig (16). Sensors and control tools can lead to substantial energy savings and prolong the lifespan of lamps and ballasts by automatically adjusting lighting according to the time of day, task requirements, daylight availability, and occupancy as in fig (17). personal lighting controls, which enable space users to adjust lighting based on their needs, and networked control systems integrated into Building Management Systems (BMS) or Energy Management Control Systems (EMCS), can improve user satisfaction and energy efficiency.[31].



Open-loop daylight sensors operate in applications where precision is less critical, such as corridors.

Closed-loop daylight sensors operate in applications where maintaining a targeted light level is crucial, such as private offices.

Fig 16. Using daylight sensors to control natural lighting according to the function of the space at the CSU Office of the. Chancellor.

Fig 17. Some lighting control devices.

3. the Case studies:

Group of global administrative buildings that rely on technological methods in lighting systems have been selected according to specific standards to achieve the study's objectives, these buildings are classified as sustainable buildings according to grading systems as; LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Method) global environmental certification.

The selected projects are contemporary projects, as the paper displays the most famous global administrative buildings established and certified as sustainable buildings from 2004 to 2024. Moreover, the required data for these buildings are declared which make ease to derive clear lighting strategies used in them. moreover, the chosen case studies shows diversity in terms of varying climatic regions.

3.1 The Edge building

- Location: Amsterdam – Holland.

• Architectural designer: PLP Architecture.
• Opening year: 2015.
• Evaluation: BREEAM of 98.36%.
• Area: 40,000 m2.
• Climatic regions: The city of Amsterdam is located between 52°N and 4°W. Its climate is moderate oceanic (Cfb) according to the Köppen classification

3.2 One Angel Square building

Location: Manchester- United Kingdom.
• Architectural designerLord Norman Foster of Foster + Partners.
• Opening year: 2013.
• Evaluation: BREEAM of 95.16%.
• Area: 30.483m2.
• Climatic regions: The city of Manchester is located between 53°N and 2°W. Its climate is moderate oceanic (Cfb) according to the Köppen classification.

3.3 Genzyme New Head Office Center building

• Location: Cambridge – USA.
• Architectural designer: Behnisch Architekten.
• Opening year: 2004.
• Evaluation: LEED platinum certification, 52 points.
• Area: 32,528 m2
•Climatic regions: The city of Cambridge is located between 42°N, 71°W. Its climate is continental (Dfa) according to the Köppen classification.

3.4 Siemens - Corporate Headquarters building

• Location: Munich - German.
•Architectural: Henning Larsen Architects Opening year: 2016.
• Evaluation: DGNB and the LEED standard in platinum.
• Area: 45000 m2.
•Climatic regions: The city of Munich is located between 48°N, 11°W. Its climate is continental (Dfb) according to the Köppen classification.

3.5 2100 L Street NW building

• Location: Washington, DC - USA.
• Architectural: WDG Architecture
• Opening year: 2020.
• Evaluation: LEED Platinum/ WELL Health-Safety Rated.
• Area: 17651.58m2.
• Climatic regions: The city of Washington is located between 39°N, 77°W. Its climate is a humid subtropical (Cfa) according to the Köppen classification.

3.6 J8 Office Park building

• Location: Bucharest, Romania
• Architectural: Chapman Taylor
• Opening year: 2021.
• Evaluation: Breeam Outstanding
• Area: 54.000 m2.
• Climatic regions: The city of Washington is located between 44°N, 26°E. Its climate is moderate continental (Dfa) according to the Köppen classification.

4. Analysing the lighting strategies used in the chosen buildings:

4.1 Natural lighting systems:

4.1.1 the design of the building and its envelope

The Edge Building: Designed with its longest side facing north and south, and the shorter sides facing east and southwest/northwest. The exterior features varied glass sizes, with sloped glass on the north facade that tilts towards the west, extending to a glass roof for natural light penetration. Window sizes decrease on the east, west, and south facades, utilizing fins for shading [41].

One Angel Square: Oriented southward to maximize sunlight in the courtyard. Its triangular shape ensures offices face south, northeast, and northwest, avoiding low eastern and western sun impacts. Upper floors decrease gradually southward, enhancing internal lighting distribution. Surrounding land increases natural light penetration and enhances daylighting [33].

Genzyme New Head Office Centre: Facades face northeast, southeast, northwest, and southwest, with the main facade on the northwest. The building envelope consists of glass on all four sides, with offices distributed around a central courtyard. Adjacent buildings reflect light onto its facades, increasing natural lighting [37].

Siemens - Corporate Headquarters: Facades face northeast, northwest, southeast, and southwest, utilizing surrounding land and building facades to enhance natural lighting within the building.

2100 L Street NW: Main facade faces southeast, with other facades facing north, south, east, and west. Glass facades reflect light onto the building, enhancing daylighting.

J8 Office Park: The main facade is on the northwest, with other facades facing east, southeast, and southwest. It includes an outdoor courtyard surrounded by buildings and land that play a crucial role in reflecting light onto its facades. fig (18) shows the horizontal plan of building orientation and the main facade direction of buildings.

The Edge Building -north facade

One Angel Square Building - South facade

Genzyme Building - Northwest facade

Siemens Building - southwest facade

2100L Street NW Building - Southeast facade

J8 Office Park Building - Northwest facade

Fig 18. The horizontal plan shows the building orientation - the main facade direction of buildings.

4.1.2 Advanced glass systems for sustainable natural lighting

The Edge Building Utilizes hollow cavity double-layered glass in its windows to enhance working conditions and provide natural light. Thermal glass is used on the north facade, while smart liquid crystal glass on the south facade automatically adjusts shading as needed based on sensor systems[32].

One Angel Square: Features a double-layered facade composed of two glass layers to create an environmental buffer zone. It consists of 3157 glass panels, with a gap increasing from 800 mm at the top and bottom to 2.5 meters in the middle, enhancing thermal insulation. The outer layer is comprised of brise soleil, contributing to its functionality[33].

Genzyme New Head Office Center: Designed with 800 windows across its facades to maximize daylight. The exterior envelope includes 46% single glass and 22% solid cladding, with 40% of the exterior surface being double-layered glass separated by a four-foot depth to optimize thermal conditions. The outer glass layers have low-emissivity coatings for improved thermal insulation. [37]

Siemens - Corporate Headquarters: Workspaces along the extensive floor-to-ceiling windows are designed to maximize sunlight utilization. Adaptive glass facades control internal light based on sunlight intensity and time of day, reducing glare and excessive heat while enhancing visual comfort inside the building[38].

2100L Street NW: Designed with adaptive glass extending from floor to ceiling to maximize natural light efficiency inside the building[39].

J8 Office Park: Uses double-glazed glass with a leakage prevention structure, and the outer panels are designed to reflect sunlight[40]. Figure (19) shows size of the glass openings for the building envelope.

North - South façade of The Edge Building

One Angel Square Building — Genzyme Building

Siemens Building — 2100L Street NW Building — J8 Office Park Building

Fig19. size of the glass openings for the building envelope.

4.1.3 Shading systems:

The Edge Building: Sun louvers are used as solar panels and deep openings acting as horizontal and vertical louvers on the south facade, providing additional shading for office spaces. Vertical louvers are also employed on the east and west facades[32].

One Angel Square: Utilizes louvers shaped as mullions between the double envelope layers to provide daylight to all users by shading the inner glass layer. Horizontal louvers are used at the top of the facade with protruding ceiling slabs to shade the spaces. Motorized blinds are used to shade office spaces overlooking the courtyard on the southeast and southwest sides, as well as external facades to protect against glare[33].

Genzyme New Head Office Centre: Features a double-glazed facade separated by a four-foot-deep gap to maintain thermal conditions inside the building. "U"-shaped blinds are used to redirect light towards ceiling panels to increase natural light penetration depth. Perforated louvers at the lower section reduce glare, and the blinds adjust automatically based on sunlight position, closing at night to reflect artificial light into the spaces after dark[37].

Siemens - Corporate Headquarters: Employs fixed and movable horizontal sun louvers to provide shading throughout working hours.

2100L Street NW: Uses stainless steel architectural mesh (Mashrabiya) as shading devices to reduce solar heat gain, glare, and improve indoor lighting quality[35].

J8 Office Park: Protrusions around openings act as sun louvers, along with the use of blinds to control interior light and reduce glare, ensuring a comfortable working environment for occupants. Fig (20) shows the shading systems used in buildings.

louvers in The Edge-One Angel Square Building

curtains and double skin façade in Genzyme Building — Mashrabiya in 2100L Street NW

louvers in Siemens - J8 Office Park Building

Figure 20. The shading systems used in buildings.

4.1.4 *lighting enhancement systems in the internal spaces of buildings:*

The Edge Building: Double-glazed glass is used in the atrium roof to maximize natural light. White suspended ceilings in interior spaces enhance light diffusion. Glass walls facing the atrium and some office spaces promote light penetration and connectivity between spaces and occupants. Wooden cladding is used on some atrium walls, while beige wooden flooring enhances light reflection and creates a refreshing environment[41].

One Angel Square: Features a suspended ceiling in office spaces with a height of 2.80 meters from the finished floor. The curved and graded design of the atrium roof covers 60% of the atrium with a solid glazing pattern, controlling light entry and providing external views to offices. Glass walls separate internal spaces and administrative divisions, with white walls enhancing transparency and connectivity. Office spaces vary with grey and beige carpets, complemented by non-glossy white and beige office furniture to facilitate light diffusion and avoid glare[42].

Genzyme New Head Office Center: Uses glass in the atrium roof with reflective elements to enhance natural light entry. Suspended ceilings inside office spaces reflect light from openings inward. Glass walls are used to separate internal spaces, promoting transparency and connectivity among employees. A "light wall," vertical illuminated curtains, on the atrium side enhance light reflection and penetration. Beige wooden floors certified by the Forest Stewardship Council (FSC) offer office occupants environmental-friendly choices. Prisms and water planes are used to reflect natural and artificial light into the building[37].

Siemens - Corporate Headquarters: Carefully designed decor reflects and distributes natural light effectively throughout all internal spaces. Materials and colors aid in enhancing light diffusion, ensuring even and appropriate natural light throughout the premises, contributing to a comfortable indoor environment.

2100L Street NW: Materials and colors are selected to efficiently distribute light within internal spaces. White ceilings, light-colored floors, and furnishings, along with internal glass walls, contribute to effective light distribution.

J8 Office Park: Designed with reflective materials and surfaces internally to enhance natural light distribution and reduce shadows inside the building, ensuring optimal light distribution in internal spaces. Figure (21) shows the lighting enhancement systems in the internal spaces of buildings.

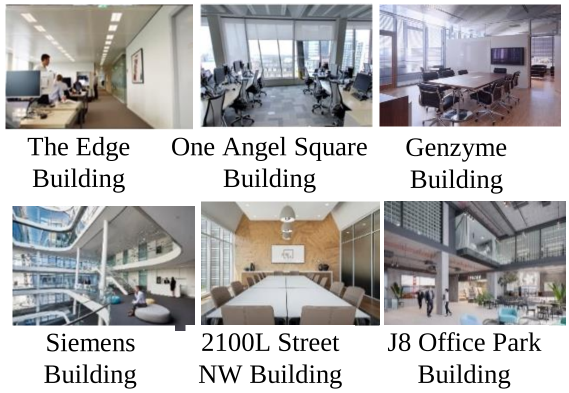


Fig 21. The color of ceiling, walls, floor and Furniture of internal spaces in building.

4.1.5 *Light assembling systems:*

The Edge Building: The north-facing atrium features 70% glass panels and a glass roof. Surrounding office spaces have a U-shaped design with glass walls, enhancing indirect natural lighting and providing external views[41].

One Angel Square: The large atrium spans the building's full height, facing south over nine floors with a sloped glass roof to maximize natural light penetration. Its five curved and graded sections aid in natural light diffusion without harsh glare[43].

Genzyme New Head Office Centre: The atrium spans 13 floors, connecting different parts of the building with a glass roof. It includes light-reflecting devices to direct and enhance natural light into internal spaces, alongside lighting systems to optimize indoor illumination[37].

Siemens - Corporate Headquarters: The central atrium is accessible from all sides, surrounded by a U-shaped main facade and several external courtyards to increase internal lighting[44].

2100L Street NW: Uses a side courtyard to enhance internal lighting, with the south facade forming an L-shape around an external courtyard to increase natural light penetration into the building.

J8 Office Park: Contains a courtyard in the northeast side to augment internal natural lighting. Figure (22) shows the lighting enhancement systems in the internal spaces of buildings.

Atrium in The Edge, One Angel Square and Genzyme Building

Courtyard of 2100L Street NW
and J8 Office Park

Fig (22) shows the light assembling systems used in buildings.

4.2 Artificial lighting systems

4.2.1 Energy efficient lighting units

<u>The Edge Building:</u> Energy-efficient LED lights developed by Philips are integrated with Ethernet technology, providing 300 lux instead of the standard 500 lux. This reduces energy consumption to 3.9 watts per square meter compared to the usual 8 watts per square meter.

<u>One Angel Square:</u> Over 11,000 lights are used, including 8,000 Luxonic lights specially designed for offices and meeting spaces. These lights use precision optics to control light and maintain high efficiency, with an expected lifespan of 50,000 hours. White and colored lights are used in reception areas and cafes to enhance the overall building layout[45]. <u>Genzyme New Head Office Center:</u> Energy-efficient halogen lights are used at night, reflecting light onto prismatic prisms to provide sufficient illumination in the atrium. This reduces electricity demand for lighting from 365 kW to 260 kW, achieving an illumination power density of 1.20 watts per square foot[37].

<u>Siemens - Corporate Headquarters:</u> High-efficiency LED lights are used for strong illumination, with indirect LED lighting partially from Osram to reduce energy demand[46].

<u>2100L Street NW:</u> High-efficiency LED lights are variably shaped according to the function of each space.

<u>J8 Office Park:</u> High-efficiency LED lights are used in offices, and UV-C / UVGI lights are employed in air handling units as an additional barrier against viruses and bacteria. [40].

4.2.2 systems for producing Renewable energy

<u>The Edge:</u> The roof and south facade feature 65,000 square feet of photovoltaic panels, reducing electricity usage by 70% compared to similar office buildings[41].

<u>One Angel Square:</u> Energy is provided sustainably through locally grown rapeseed, sourced from nearby British cooperative farms, for a Combined Heat and Power (CHP) plant. The plant operates on biofuel and waste cooking oil[43].

<u>Genzyme New Head Office Centre</u>: A 1,650 square foot array of photovoltaic panels on the roof generates approximately 24,000 - 26,400 kWh annually, contributing to peak electricity demand reduction on-site[34].

<u>Siemens - Corporate Headquarters:</u> Meets all energy consumption requirements using renewable sources. A robust rooftop photovoltaic system generates nearly one-third of the building's electricity needs.

<u>2100L Street NW:</u> Utilizes a solar panel array on the roof to generate power and reduce electricity consumption.

<u>J8 Office Park:</u> Solar energy systems installed on building rooftops contribute to meeting a portion of the building's energy needs.

4.2.3 Control systems:

<u>The Edge:</u> Features smart sensors supported by neural networks to continuously measure occupancy, movement, and light levels. Philips Lo E LED system is used throughout office spaces to reduce energy requirements, allowing efficient space management and user comfort. Individual lighting control via smartphones enhances comfort and efficiency[32] [48].

<u>One Angel Square:</u> Lighting fixtures from Luxonic are connected to daylight sensors and DALI dimming controls. This system enables automatic lighting adjustment based on natural light levels and occupancy, significantly enhancing energy efficiency.

<u>Genzyme New Head Office Centre</u>: Offices are equipped with sensors for image, occupancy, and daylight, leading to substantial energy savings. Employees have manual control over lighting units using wall switches. Automated control of blinds, heliostats, and light walls optimizes light distribution based on weather conditions and lighting needs.

<u>Siemens - Corporate Headquarters:</u> The building is equipped with motion sensors and light sensors that adjust lighting based on presence and natural light levels in rooms. This helps reduce energy

consumption and extend the lifespan of lighting fixtures. Employees can adjust lighting in their individual spaces to suit their personal needs, promoting comfort and productivity.

<u>2100L Street NW:</u> Smart lighting control systems and daylight sensors are employed to optimize lighting brightness and distribution according to user needs and external lighting conditions.

<u>J8 Office Park:</u> Uses DALI control systems to adjust lighting brightness and distribution based on user preferences and external lighting conditions, enhancing energy efficiency and user comfort.

5. Results:

The systems used in the selected buildings were identified and it was concluded that all buildings used technological systems for both natural and artificial lighting, including building envelope systems for light enhancement, lighting enhancement systems in internal spaces of buildings, and light assembling systems. Additionally, they utilized technological artificial systems such as energy-efficient lighting units, systems for producing renewable energy, and control systems, with diversity in their implementation methods to achieve sustainable lighting as follows:

1-All buildings prioritized proper orientation, such as tilting towards the northeast and northwest directions to aid in shading the building with increasing sunlight height. They also avoided low sun angle exposures in the east and west directions and used suitable shading systems with shaping in the building mass to achieve maximum benefit from natural lighting.

2- All buildings focused on utilizing the surrounding land extension to penetrate light into interior spaces, while many buildings have benefited from light reflections from adjacent building facades and surfaces, the nearby surfaces were not available for some of them.

3- All buildings used full-building glazing, covering the entire height of the space, along with the use of narrow openings on some facades in a few buildings.

4- The majority of the buildings utilized Skylight Openings system in the atrium roof to capture natural light with using glass and some of them used polycarbonate material. On the other hand, there was no need to use the system for lighting in the rest of the spaces.

5- Transparent materials such as laminated glass and technologically processed glass were used in all buildings for openings, while Polycarbonate material was used in in a few of them.

6- All buildings used both internal and external shading systems, each employing different shading techniques. However, they all utilized louvers and curtain.

7- All buildings achieved benefit from light reflections on interior elements by using reflective colours on ceilings, walls, floors, and furniture. They also employed transparent materials in ceilings and walls, and used reflective materials on floors and furniture. Additionally, a few buildings utilized reflective panels in ceilings, walls, and partitions.

8- The use of light assembling systems varied among the buildings, The majority of them were used for atriums followed by courtyards with the fewest being used for courts. Additionally, sunlight collecting devices were used sparingly.

9- All buildings used energy-efficient artificial lighting units, especially various forms of LED units, coupled with sensors.

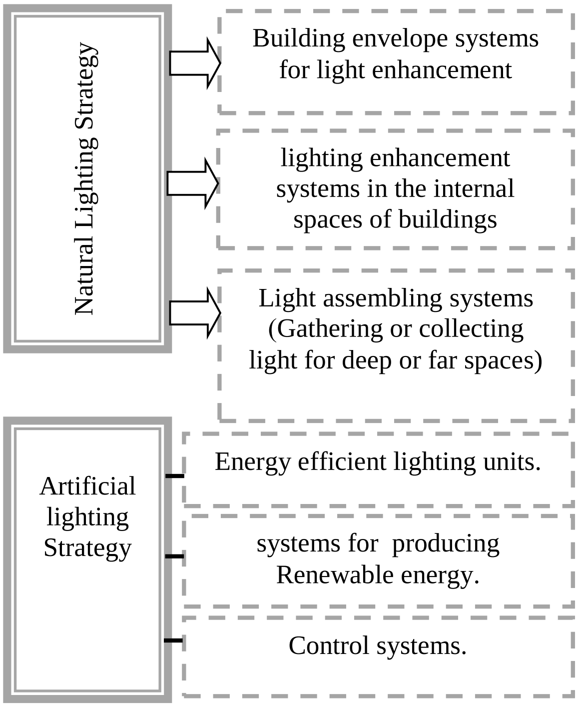
10- All buildings used systems for producing renewable energy to reduce artificial lighting costs. Photovoltaic cells were installed in the majority of the buildings, while a smaller number utilized organic materials.

11- All buildings utilized automatic lighting control systems to ensure visual comfort and energy savings throughout working hours. Manual control options were also available to enhance comfort for occupants.

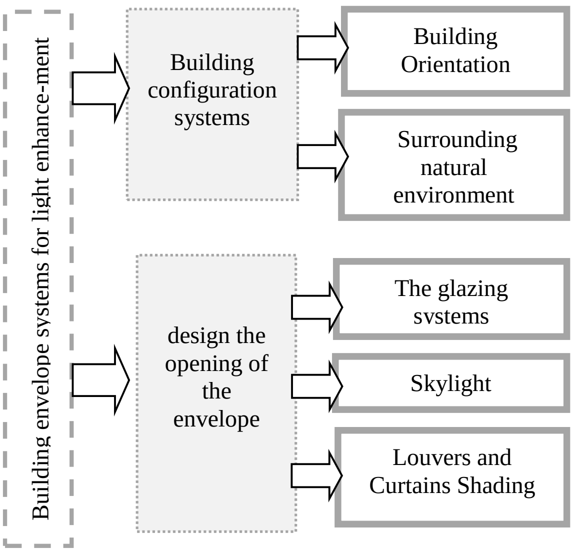
12- Advancements in lighting technology have led to the introduction of new unconventional elements, such as relying on illuminated furniture units instead of traditional lighting fixtures to enhance interior lighting. Additionally, new methods for shading facades through three-dimensional units like fabric canopies have been employed, However, these were not utilized in the selected study buildings.

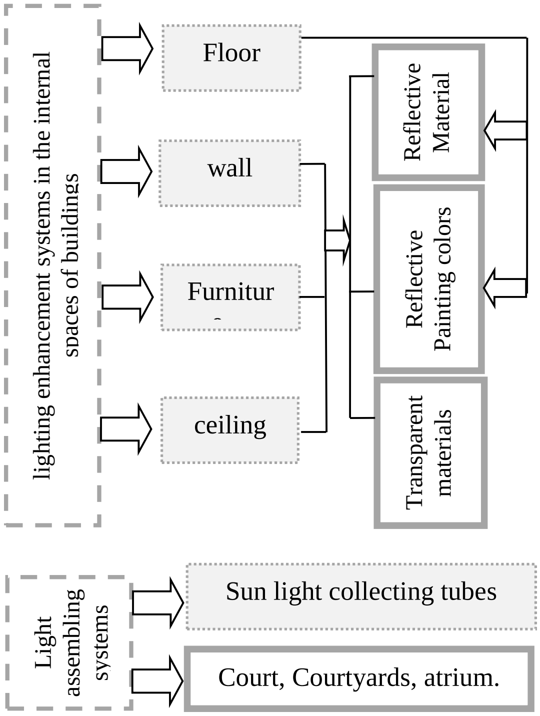
13- Most sustainable strategies used in building lighting tend to involve multifunctionality of a single element. This includes using technologically advanced glass for exterior windows to provide natural lighting while also offering shading and heat protection. Utilizing shading systems to reflect external light into interior spaces further enhances natural lighting. Additionally, using renewable energy sources to power shading systems improves energy efficiency.

From the above, we can deduce the strategy adopted in sustainable lighting within administrative building spaces from the period 2004 to 2024, which includes both natural lighting strategy and artificial lighting strategy, each comprising a number of systems as shown in the following figure:

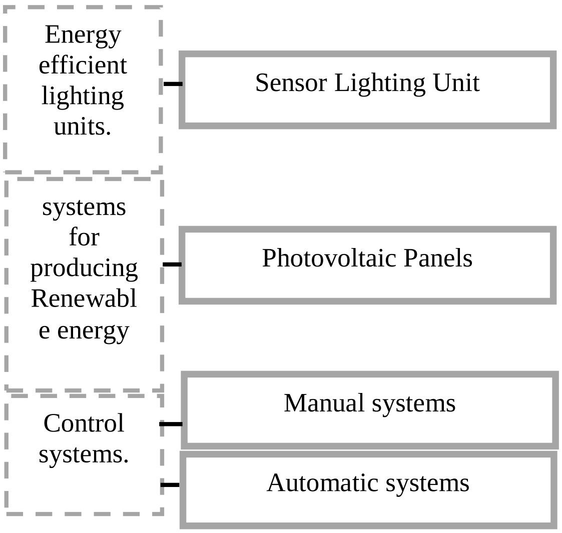


the systems used in the buildings vary in the number of methods employed for sustainable lighting, although they have participated in several of them. Firstly, the natural lighting strategy, where all buildings agreed to use these systems as shown in the following figure:





Secondly, the artificial lighting strategy, where all buildings agreed to use these systems as shown in the following figure:



Consequently, combining both natural and artificial lighting strategies in buildings achieves sustainable lighting in indoor spaces, providing visual comfort while saving energy.

6. Conclusion

The study in this research relied on deriving clear strategies for the sustainability of natural and artificial lighting in administrative buildings, in accordance with the building location and economic conditions. This was achieved by studying a range of technological lighting methods and then investigative their application in some globally recognized administrative buildings that have received LEED or BREEAM certification.

The results confirmed that these buildings follow clear sustainable strategies for integrating natural and artificial lighting, which include a set of basic technological systems that vary in the number of methods employed for sustainable lighting, although they share many commonalities.

Administrative buildings should work on reviewing and evaluating current systems and updating them according to these strategies, benefiting from the successful experiences of buildings certified with LEED and BREEAM. Additionally, future research should focus on developing smart lighting technology using artificial intelligence to further improve energy efficiency in lighting systems. It is also essential to study the economic benefits of applying sustainable lighting technologies in administrative buildings compared to traditional systems. This helps to enhance knowledge and practical application of sustainable strategies in lighting administrative buildings, contributing to creating more comfortable and efficient work environments both environmentally and economically.

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