Assessment of Daylighting Strategies in Convention Centres: A Review from 1990 to 2023

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ABSTRACT

The main goal of a convention center is to provide a productive environment for different events, which they must do by meeting energy efficiency and sustainability requirements. Being a commercial building, it is known for consuming energy in large amounts, which should be mitigated to ensure sustainability. Daylighting is a significant technique in contemporary architecture that contributes to building energy savings, helps to reduce dependence on artificial lighting, provides connections to outdoor spaces, and influences users' comfort. The study aims to investigate and review the daylighting strategies that are used in convention centers. To achieve this, literature, articles, and websites were reviewed to better understand daylighting and how it is applied in this building type. The study adopted a systematic review and discussed the results descriptively, and it showed that this technique is rarely used in this building type. This could result from a lack of daylighting consideration at the conceptual stage of the building design. Hence, it is recommended that designers understand this technique in order to properly implement it in convention centers and other building types. Further research can be carried out on how daylighting influences user comfort and satisfaction in other building types for adequate implementation in modern-age construction.

Keywords: Daylight, Daylighting Strategies, Convention Centre

1. INTRODUCTION

A convention center is a commercial building that is designed for conventions, large shows and events, public gatherings and meetings, and concerts. It is a single building or group of buildings designed together for holding rallies, meetings, and/or seminars, which can also be adapted for particular events such as concerts. Luster (2017) noted that it is where groups of individuals come together to share common interests. Convention centers serve as icons for their communities and attract huge numbers of visitors. Their primary purpose is to provide a productive environment for different events, which they must do by meeting energy efficiency and sustainability requirements. Shukla and Sharma (2018) discovered that commercial end-users, who account for 20% of the energy delivered globally, consume a significant amount of energy in the building sector. According to the U.S. Energy Information Administration (2018), the total amount of energy consumed by electricity in commercial buildings has increased from 38% in 1979 to 61% in 2012 in the U.S. This shows a steady rise in the use of energy in commercial buildings that is majorly due to the use of electricity, and the heating, ventilation, and cooling (HVAC) systems. Daylighting is a technique that can be used to mitigate energy usage in commercial buildings.

Daylighting involves using natural light to illuminate a space in a building. It is a technique that harnesses natural light to achieve specific lighting effects in the building. Daylighting is providing light in a room by controlling the light placement and fenestrations (Nikolai and Erkki, 2008). It is a significant technique in contemporary architecture as it contributes to building energy savings, helps to reduce dependence on artificial lighting, provides connections to outdoor spaces, and improves user comfort (Ing, 2017). It is necessary to have adequate indoor environment quality (IEQ) as it reduces users' medical bills, increases productivity, and increases work performance (Brager, 2013). Daylighting contributes to adequate IEQ by enhancing the quality of a room when employed in architectural designs.

In recent years, researches on daylighting in other building types have been carried out, however, little to no research has been done on daylighting in convention centers, which the study aims to explore. The study aims to investigate and review the daylighting strategies that are used in convention centers. To achieve this, the study presents the following objectives;

1. To investigate what daylighting is,
2. To examine the daylighting strategies, elements, and approaches, and
3. To identify the daylighting strategies used in convention centers

A review of works of literature on daylighting in convention centers was conducted to achieve this. Studies related to daylighting were analyzed thoroughly. This study is necessary as it would help designers and architects understand the concepts of daylighting and how it can be implemented in this building type. It is also important as it helps in achieving environmental sustainability and serves as a starting point for further research in other areas of daylighting and convention centers.

2. METHODOLOGY

Identifying the existing daylighting strategies discussed by related studies is important as it helps to broaden the general understanding of daylighting. This was conducted with the intention of focusing on the daylighting strategies that are generally used. Thus, it is important to understand how these strategies can be effectively adopted and the possible limits to this technique in convention centers. Based on this, the approach used in this study is a qualitative approach, adopting a systematic literature review method. This was achieved by analyzing journal articles and websites that related to daylighting strategies and convention centers. The search for articles consisted of two stages. The first stage included determining the academic databases: Google Scholar and Science Direct. These were chosen because they are reputed to be among the largest online databases of peer-reviewed materials in the field of daylighting. Stage two involved using keywords to search for core content in the databases. The keywords inputted were: ("daylighting strategies", and "daylighting in convention centers").

A total of 46,178 items (26,978 on Science Direct and 19,200 on Google Scholar) were found based on the keyword "daylighting strategies" from the years 1990 to 2023. However, there was no item on "daylighting in convention centers" that was found in both academic databases. Since the study is focused on assessing daylighting in convention centers, materials that discussed daylighting in detail were chosen to understand the strategies of daylighting and to provide recommendations on its adoption in convention centers. With this, initial screening was done by identifying articles with the aforementioned items in their keywords, and this led to 306 journal articles, conference papers, and research reports. Through thorough analysis of the abstract of the identified items, 281 items were removed due to their irrelevance from the focus of the study, and 65 were chosen and used. About 10 other items were studied from other websites that had short articles discussing various aspects of daylighting, such as the Illuminating Engineering Society of North America (IESNA) Lighting Handbook website and Major Industries website, to better understand daylighting in other fields of study, making a total of 75 articles. The review of all the articles and their contents resulted in the generation of qualitative data that help develop the study.

3. CONVENTION CENTRES

A convention center is a type of commercial facility that can hold huge crowds for events like conventions and concerts. The economic and industrial activities in cities have changed due to modern convention centers. It is one of the key players in the tourism and events industry, making important economic contributions to its location (Wu and Weber, 2006). The preference of conference attendees and shifting economic conditions have both had an impact on the evolution of convention center architecture over time. From being just a big hall, they have developed into a multipurpose structure with a main hall and auxiliary halls for other uses including lectures, seminars, and banquets. Based on research carried out, it was discovered that there are no types of convention centers, however, there are major types of conventions, and these include comic conventions, science conventions, science fiction conventions, and technology conventions. Science fiction conventions are events where individuals with similar interests in various genres can engage in and discuss the world of science fiction (Childers, Governor, Greer, and James, 2023). Convention centers can also be classified into categories based on regions, which include international conventions centers, national conventions centers, regional conventions centers, and local conventions centers. Bhandari (2005) noted the features of a convention center, which are exhibition spaces, conference spaces, auditorium halls, multipurpose halls, recreational spaces, and administrative spaces, with restaurants and galleries. A good example of a convention center is the Colorado Convention Centre in Colorado, U.S.A. (Plate 1). The Colorado Convention Centre is a multi-purpose convention center that is currently the 12^{th} largest convention center in the United States. It was designed and planned by more than 100 professional planners working with architects to create a state-of-the-art facility. The first development in 1990 spanned 74,000m^2 and included an exhibition hall, a major ballroom, and five meeting rooms. Later, in 2004, it was expanded to an area of 200,000m^2, adding additional meeting rooms, two ballrooms, and an indoor amphitheater. Since it was opened, the center has hosted 400 events annually on average. Due to its architecture and location in the city center, it has evolved to be one of Denver's iconic landmarks.

Plate 1: Aerial View of The Colorado Convention Centre, Source: Rubino (2020)

4. DAYLIGHTING

Light can be described as the medium that discloses texture, color, space, and shape to the eye (Simon, 2013), for without it there is no vision. The source of daylight is the sun. The sun provides light for different parts of the earth at different periods of time because of the rotation of the earth, according to IESNA. The sun is a clean, sustainable source of energy, which is also abundant and the most significant renewable energy source amongst others (Omer, 2008). This light is gotten from the sun in two forms; direct sunlight – where the light rays directly enter the space, and diffused light – where the light rays are diffused by the atmosphere and clouds. Alrubaih *et al* (2013) noted that there are different sky conditions that affect the amount of daylight provided, which are a clear sky – when the sun provides the brightest light rays that create shadows, a cloudy sky – when there are constant changes between direct sunlight and diffused daylight, and an overcast sky – when the sky provides the brightest atmosphere in an outdoor space. On a cloudy day, persons' inability to perceive the colors from light can influence their levels of energy and mood (Edwards and Torcellini 2002).

Daylighting is an important factor to consider in design because of its many benefits. Al-Ashwal and Hassan (2017) postulated that in building sustainable designs, an alternative source of light to artificial lighting is daylight. The daylighting system collects and distributes sunlight in a building for efficient interior illumination, thereby adding to its sustainability, and this technology is already available and growing rapidly (Castanheira, Souza, and Fortes, 2015). It helps in reducing the dependence on artificial lighting and energy consumption. Daylight provides a better lighting environment than electrical light sources because according to Franta and Anstead (1994), "daylight…matches the visual response that humans have compared with all other light through evolution." Santamouris *et al* (1994) investigated the constraints and possibilities that came with various energy conversion techniques in 186 office buildings in Greece. They discovered that the use of natural lighting can lead to major energy savings. To maintain a comfortable visual environment, Vu *et al.* (2021) advised that individuals should receive enough sunlight during the day and avoid being exposed to excessive light.

Daylighting can be an effective factor that helps improve the health of the occupants. Dr. Ott (Ott Biolight Systems, Inc. 1997a) stated that just like water and food, light serves as a supply of nutrients for the body's metabolic activities. The stimulation of vital biological processes in the brain can be done by natural light. The production of vitamin D-3 is done by ultraviolet irradiation of the human epidermis, and over 90% of the main forms of vitamin D-3 are dependent on sunlight (Whang *et al.,* 2019). Haddad (2010) stipulated that by adding daylight, a space can be transformed into one that fosters positive feelings of consciousness and residence, thereby having desirable effects. Boyce, Hunter, and Howlett (2003) discovered that advanced sleep phase disorder is a common problem of the elderly, and being exposed to daylight at an appropriate time can help resolve this problem. Heerwagen (1986) used various window views to evaluate the impact of light on inmates' health. He found that inmates with views of buildings and the prison courtyard experienced considerably higher rates of stress-related illness than those with views of the mountains or a meadow. Valles *et al.* (2018) carried out research that showed that a test group that was frequently exposed to the sun developed a reduced risk of colorectal cancer during the summer.

These benefits can contribute to a suitable and sustainable environment. However, there are disadvantages as there are advantages. The presence or absence of daylight can affect how people perceive space and elicit intense emotional reactions (Systems and Cycle, 2017). Improper daylighting can cause health issues. Heat gain and glare can also cause discomfort in the space for the occupants (Pierson, Wienold, and Bodart, 2018). Kreider, Curtiss, and Rabl (2009) noted that although heat gain is caused by the entire building envelope being exposed, it is commonly due to the glazing present which leads to the majority of cooling loads. Overheating can also occur due to longtime exposure of internal surfaces and furnishing to direct sunlight (De Luca, 2020).

4.1. Daylighting Strategies, Elements, and Approaches

Ander (2003) identified two broad strategies of daylighting technique, which are side-lighting and top-lighting. Sidelight is light that comes from the side of the building. It uses vertical surfaces to bring light into the building. An advantage of this strategy is to create various views of the exterior environment and provide ventilation. Gherri (2015) stated that to illuminate a room from only one side, one must consider the design of the aperture, its size, and its positioning with respect to the interior and the façade of the building. Top-lighting is a strategy that uses apertures like skylights, light pipes, and clerestories. It is located on the roof of the building. Its advantage is that it is not constrained to wall orientation, and it allows for a flexible design. It also helps to reduce the amount of electricity used by artificial lighting.

In wintertime in Beijing, Wu *et al.* (2009) looked into the effectiveness of one side-lighting solar light pipe and two top-lighting solar light pipes. The results demonstrated that solar light pipes via side-lighting outperform those with top lighting. Afiq, Zulkeflia, and

Hassan (2019) studied these daylighting strategies for laboratory buildings and found that side-lighting at the north and south façades is the best choice since it delivers more daylight. Lawrence, Roth, Crawley, and Brodrick (2008) postulated that if skylights are properly installed in various kinds of building types and climates, annual lighting energy consumption might be reduced by 35% to 55%. Fig 1 shows how the daylighting strategies function in a building.

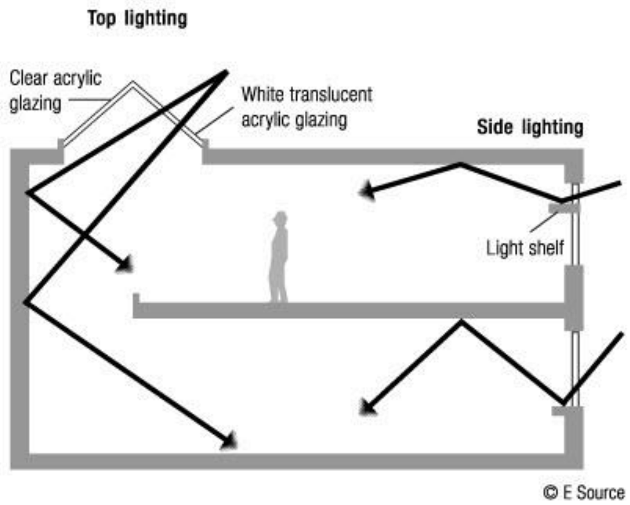

Fig 1: Various Daylighting Strategies, Source: (FriendlyPower.com)

Daylighting is a technique that requires strategies to perform, and these strategies have elements that it utilized to create adequate IEQ. The elements discovered are discussed below.

1. Windows

A window is the most common daylighting element known in every aspect of life. It is a light framework made of timber, plastic, or metal that contains glass or glazed frames. It is placed on a wall or roof of the building to allow light and air. There are different types of windows, some including louvres, awnings/casements, clerestories, sliding, fixed, and corner windows. Shi and Chew (2012) discovered that increasing the number of windows and their size is the best approach for achieving more daylight in a space. Windows are crucial for controlling the indoor thermal environment and interior daylighting in buildings. Workers in windowless surroundings scored worse than those in windowed situations when Boubekri *et al.* (2014) evaluated the effect of windows and daylight exposure on workers' overall health and sleep quality, which then gave them more light exposure and generally impacted their health positively. Although there are many energy-saving windows, including radiative cooling glass and low-emissivity glazing (Abundiz-Cisneros *et al.*, 2020; Chen and Lu, 2020), they continue to be considered as the least energy-efficient part of building envelopes due to conflicting energy demands in different seasons (Alrashidi *et al.*, 2020). Hee *et al.* (2015) discovered that in winter, the windows result in at least 30% energy loss, whereas the majority of solar radiation entering through the window will increase the cooling load in summer. Boyce, Hunter, and Howlett (2003) noted that windows are strongly preferred in workplaces for the daylight they allow and the view out they provide, provided they do not cause too much thermal or visual discomfort or loss of privacy.

2. Light Wells

A light well is a top-lighting aperture that directs daylight into the building. It is an air shaft, usually unroofed or roofed, that allows light and air to reach a dark or unventilated area in a large building (Narasakia, Satob, and Yamanakaa, 2003). The light well's design simultaneously distributes light and protects the viewer from intense sunlight (DiLaura, Houser, Mistrick, and Steffy, 2011). Kristl and Krainer (1999) postulated that to introduce daylight into central areas of a building and control heat gain and loss at the same time, there are three different light-guiding systems; the best light-guiding system is a pair of light wells with a wide upper section and a narrow bottom section into which a reflecting wall is inserted. Fig 2 shows the individual light well (a), the semi-individual light towards the interior and from the conservatory well (b), and the joint light well (c). The broken lines mark the expected range of direct and reflected light.

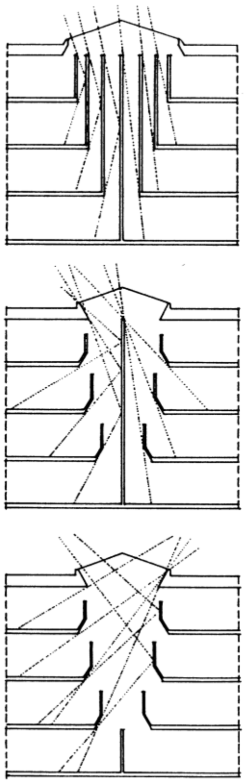

Fig 2: How light wells function in a multi-story building, Source (Kristl and Krainer, 1999)

3. *Light Shelf*

A light shelf is a horizontal surface that bounces natural light off into the building. It is a side-lighting element that is placed above the eye level and is made of reflective materials such as metal, glass, or plastic. They are most effective on the south-facing side and not on the other sides. The material used has a matte finish to diffuse direct sunlight that comes on it (Barber, 2007). They can also serve as a shading device for the room adjacent to the windows. The use of horizontal light shelves enhances the illuminance in office spaces, and by tilting the external part of the light shelf, the illuminance level increases (Mohapatra, Kumar, and Mandal 2019). Kontadakis et al. (2018) reviewed the designs of light shelves and discovered that the parameters that affect their performance are their geometry, material type, reflectance type, room geometry, position, and climatic conditions. The adoption of light shelves can improve the daylighting quality near the windows while somewhat reducing the useful daylight illuminance (UDI) level at the back of the room (Berardi and Anaraki, 2015). Kontadakis et al. (2018) also provided a review of light shelves considering the parameters affecting their performance over 34 years. It was discovered that light shelves perform better at the south-facing façade. Lee, Kim, Seo and Kim (2017) noted that light shelves may increase the energy consumption for heating during winter by preventing natural light from entering the space. Lim and Ahmad (2015) concluded that designing a light shelf by responding to the changing sky conditions and direct sunlight is more important than considering the façade orientations of a building. If appropriately designed, exterior light shelves can serve as overhangs and shade for lower windows, which is preferable to traditional shading methods (Claros and Soler, 2001). The interior and exterior shelves can affect different indoor tasks positively or negatively (Fig 3).

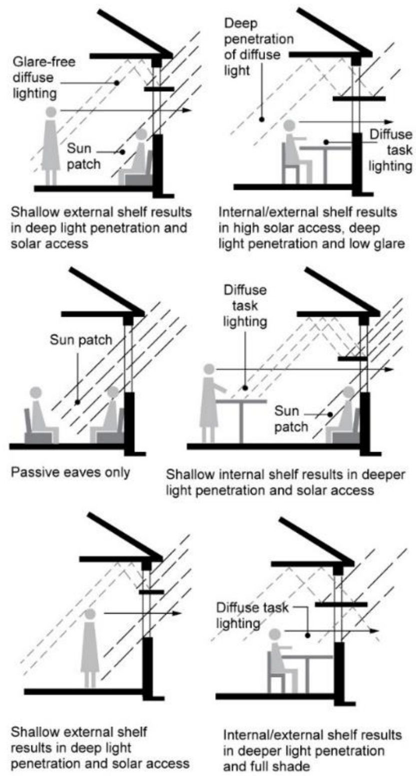

Fig 3: How light shelves function in a house, Source: (Milne and Riedy, 2013)

4. Light Pipes

The light pipes system is a type of top-lighting that uses reflective tubes to focus light on a particular area of a building. It is a lighting fixture that gets direct light from the sun. It collects sunlight directly from the building surface and transfers it to different cores. Light pipes are light transport systems that help to distribute light into deep open plans (Heng, Lim, and Ossen 2020). Light pipes work by placing a device on an external closing element which collects light from the sun, and redirects, in some cases, concentrates or collimates the incident light, and situating a diffuser inside the building that distributes the collected light into the deep zone of the rooms for better illuminance distribution (Canziani, Peron, and Rossi, 2004). Horizontal light pipes have the capacity to allow daylight into the depths of buildings (Obradovic and Matusiak, 2020).

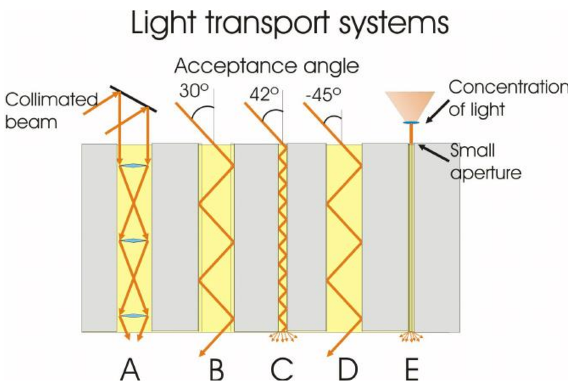

Fig 4: Different light pipe technologies, Source: (Garcia-Hansen and Edmonds, 2003)

5. Skylight

A skylight is a type of window that is located on the roof of a building. Skylights usually makeup part or the entire roof of a space of a building and typically allow occupants within to see the outside environment as well as to allow sunlight to enter the building via top lighting (Onubogu, Chong, and Tan, 2021). The size varies depending on the space it is placed in. It can be used in small private rooms and large open spaces. It is also commonly used for atriums in commercial buildings. Due to environmental restrictions, the use of skylights in single-storey buildings is restricted in Malaysia (Karam, Muhammad, and Abdul Malek, 2015). Domed skylights provide natural light and heat to buildings and also a connection between occupants and the outdoors (Amirabbas, Abdelaziz, Naylor, and Ramdhane, 2010).
There are also some approaches to consider when designing daylighting in buildings. This deals with the building orientation and site, building shape and area, room geometry, size and location of aperture, internal and external reflected surfaces, shading devices, and redirecting systems.

4.2. Building orientation and site

In warm regions, optimal orientation is a critical approach, thus buildings should be positioned in specific ways that have planning implications for the architect (Hyde, 2000). The south facade allows the most daylight in the building and this causes excess heat gain during the summer. This is the most suitable place to situate areas that require high lighting levels. Although the daylight from the north facade is less than the one from the south, the near-constant availability of diffused light makes this the second most ideal orientation. Alagbe, Caiafas, Olayemi, and Joel (2019) studied the passive design strategies used in the hostel buildings at Covenant University, Nigeria (Fig 5). It was discovered that the building shape and orientation provide a significant influence on how natural ventilation and daylighting are used to minimize heat gain and solar glazing. The building should be sited in a way that it maximizes available daylight through the sky exposure angle (Fig 6) (Barman, Roy, Dasputa, Scholar, and Professor, 2020).

Fig 5: Building orientation of Peter Hall, Source: (Alagbe, Caiafas, Olayemi, and Joel, 2019)

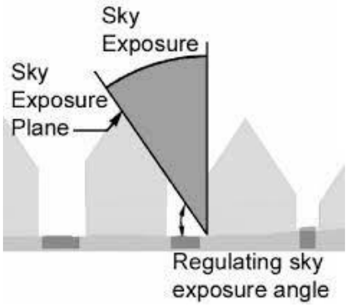

Fig 6: Regulating sky exposure angle and sky exposure plane, Source: (Barman, *et al.*, 2020)

4.3. Building shape and area

A building's geometry is one of the most crucial architectural decisions made in the early stage of design. It has a significant impact on a building's energy and daylighting performance in addition to its aesthetics and use (Yuan and Cho, 2019). Buildings with long and slender shapes allow for maximum daylight penetrations (Madu and Alibaba, 2018). The buildings can split into wings to meet land use requirements and provide access to daylight. Considering the building area would be useful in identifying the daylighting strategies and elements to use. It would also help to develop an energy-efficient and attractive space.

4.4. Room Geometry

The width, height, and depth of a room can influence the daylight that comes into the space. Susorova et al. (2013) used the ratio of room depth to width, which impacts the interaction between the internal and external walls and the light distribution in the space, to study the effects of room geometry on window energy efficiency in office buildings. The depth of the room defines the distance of daylight penetration, and the width of the room defines the area exposed to heat transfer through the quantity of daylight received. It was found that a wide and shallow room has a significant heat gain but good light distribution and daylight level. A deep, narrow room, on the other hand, has minimal heat gains but inadequate daylight levels.

4.5. Size and location of aperture

An aperture is an opening in the building envelope that allows natural light and/or ventilation. The geometrical features of windows play a significant role in providing and distributing daylight in a building (Ramesh, Geetha and Ramachandraiah, 2020). A lengthy strip of windows is ideal for maximum admission of daylight as opposed to individual windows. Although, the conventional individual windows can be sufficient if clear glazing is used because lengthy window strips can create heat gain which would contribute to heating and cooling loads. Horizontal windows provide greater light distribution as opposed to vertical windows because they create light variability and result in disturbing glare (Fig 7). Kong et al. (2022) studied the physiological responses of building users gotten from the influence of window size, sky conditions and aperture design. It was discovered that irregularly shaped aperture designs had more interest than regularly shaped designs, as well as low levels of calmness. These aperture designs would most likely elicit positive responses from the users.

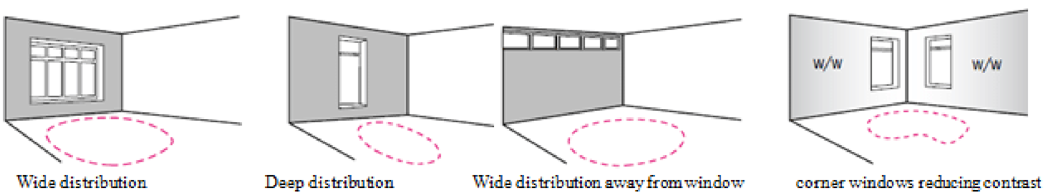

Fig 7: Effects of different sizes of windows, Source: (Loe, Rowlands, and Mansfield, 1999)

4.6. Shading devices

Shading devices assist in limiting solar heat gain and allow enough natural light and ventilation into interiors, which reduces the constant need for artificial ventilation (Alagbe, *et al.*, 2019). There are various types of shading such as blinds, solar screens, overhangs, and solar glazing.

4.7. Internal and external reflected surfaces

There are internal and external surfaces that influence the overall daylight of a space. They are some components of the daylight factor, which is the amount of daylight in a space expressed in percentage (Hopkinson, 1963). The internally reflected component (IRC) is sunlight that is reflected on an external surface to an internal surface (tables, chairs, etc.), into the space, and it constitutes 50% of the daylight factor. The externally reflected component (ERC) is sunlight that is sunlight that is reflected on an external surface into a space, and it constitutes 20% of the daylight factor (Fig 8).

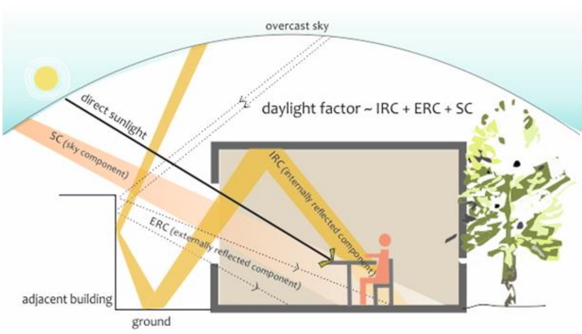

Fig 8: Components of daylight factor, Source: (NetZeroEnergy.com)

5. DAYLIGHTING STRATEGIES IN CONVENTION CENTRES

Daylighting is a crucial contributor to the use of sustainable energy and the decline in energy consumption. Convention centers as commercial buildings are examples of large energy consumers, and one major cause is lighting. Lighting a commercial building can be tricky to adequately achieve without adequate knowledge and skill. Lighting is one of the major end-users of electricity in commercial buildings (Luster, 2017). Convention centers often utilize artificial lighting such as fluorescent and LED light fixtures and barely utilize daylighting strategies. Feuling (2021) noted that some centers adopt translucent panel systems to evenly and efficiently distribute daylight throughout large indoor spaces, making them an ideal solution for event and convention centers. Introducing daylighting elements like light shelves and skylights can help improve the energy consumption of commercial buildings. Daylighting has its advantages as well as its disadvantages. Balancing daylighting against heat gains can be an uncomfortable issue for users. There is also the need to manage brightness contrast to avoid direct glare and balance light distribution. The major challenge with current energy optimizers is maintaining a balance between energy optimization and user comfort (Khorram, Faria, Abrishambaf, and Vale, 2020). With proper installation skills, these challenges can be overcome to optimize daylighting benefits.

6. CONCLUSION

Daylight is an important aspect of design and construction, and also sustainability. This study looked at daylighting, its source, strategies, elements, and approaches. The elements of daylighting include windows, light shelves, light pipes, light wells, skylights, and clerestories. Daylighting can also be improved by providing shading devices to protect against glare and visual discomfort. The building's orientation can be utilized by considering the sun and wind directions and positioning the elements in areas that best allow daylight and ventilation. Convention centers are large commercial buildings that consume a lot of energy on electricity for the lighting and HVAC systems. Implementing this technique in this building type can help reduce energy consumption and improve sustainability. However, existing studies have shown that this technique is rarely used in this building type. This could result from a lack of daylighting consideration at the conceptual stage of the building design. Hence, it is recommended that designers understand this technique in order to properly implement it in convention centers. Further research can be carried out on how daylighting influences user comfort in other building types so that it can be implemented in modern-age construction.

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