Importance of Daylighting systems in Commercial Spaces

Ar Maitreyee Joshi

Abstract— Daylighting is the process of using sunlight to illuminate the occupied space to help reduce the energy costs especially in commercial buildings as the energy usage in these space are maximum due to the lighting measures where artificial or active lighting becomes the major factor. Researchers says that in 2020, the commercial sector, which includes commercial, institutional buildings, Public Street and highway lighting consumed about 157 billion kWh for lighting. The process of daylighting includes designing of controlled amount of illumination (both diffused and direct) inside a building. With new technology and product evolution happening rapidly there is a need to incorporate the new and innovative methods of daylighting in the commercial spaces. This paper talks about different ways to inculcate daylighting in the commercial spaces to promote better occupant health, well-being and also promote sustainability by reducing the usage of active lighting systems, and also focuses on various aspects and design consideration to inculcate natural lighting in commercial spaces.

Index Terms— Artificial lighting, Daylighting, Daylight harvesting, Energy usage, Glare, Innovative daylighting system, Lightpipe, Occupant

1 INTRODUCTION

LIGHTING designing is the combination of science and art which makes it an architectural discipline. One must consider the factors quantitatively for each space to achieve the results positively. Some of the factors include: Daylight availability, energy aspect of the space, visual need of the occupant, effect of brightness pattern on visual acuity, location interrelationships and psychological effects of light and shadow.

Although the general goal of daylighting is to reduce the usage of active/ electric lighting and save energy, it is also important not to let too much of light inside the spaces which may act as a visual interference between the occupant and function of the space.

The innovative daylighting systems (IDS) seek to meet the illumination requirements in buildings, where inadequate amount of daylight is provided by the conventional daylighting systems. Many IDS have been commercially launched, but challenges, such as high initial cost, utilization difficulties, and application limitations, prevent their widespread use. Most of these challenges can be overcome, but no IDS are likely to overcome all of them at once[1]. Alternatively, a number of systems that efficiently suit different circumstances is a more practical approaches.

2 PHYSICS OF LIGHT

2.1 Light as radiant energy

IESNA defines light as visually evaluated radiant energy. If light is considered as wave similar to radio wave or A/C current wave, it has a frequency and a wave length [2]. Fig 1 shows the position of light in the wave spectrum.

Visible light constitutes a very small portion of the wave energy spectrum. Color is determined by wave length. Starting with longest wave length (red) we proceed with the spectrum of orange, yellow, green, blue, indigo and violet, to arrive at the shortest visible wave length (highest frequency).

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Fig 2 indicates the wavelength and eye sensitivity in the form of colors a normal human eye takes.

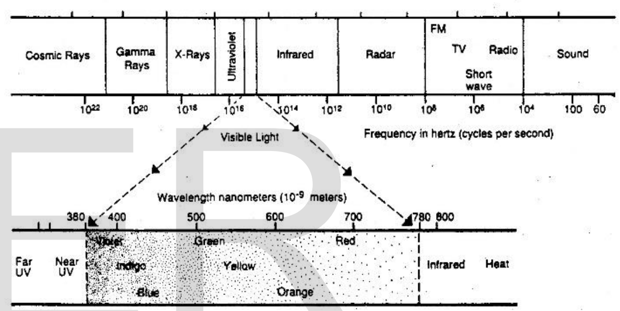

fig 1: Indicating the position of visible light in the wave spectrum.

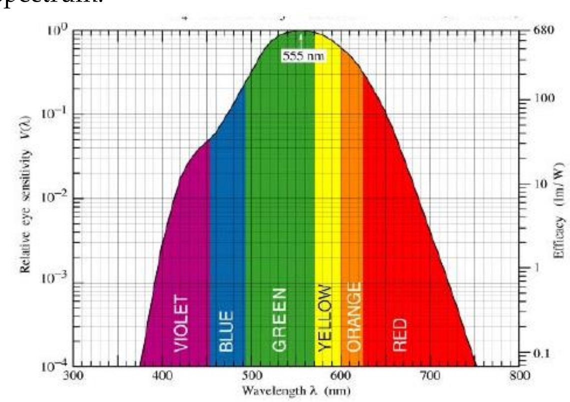

fig 2: indicating the different wavelengths

Bordering the visual spectrum are infra-red at low frequency (long wave length) and the ultra-violet at the high frequency end. Both are invisible to humans but are not so to some animals [2].

When a light source produces energy over the entire visible spectrum in approximately equal quantities, the combination appears "white".

2.2 Transmittance and Reflectance

Lighting design is possible because light is predictable [2]. The Luminous Transmittance of a material is a measure of its capability to transmit incident light. By definition, this quantity is a ratio of the total transmitted light to total incident light [3]. This factor is used for materials displaying non-selective absorption, i. e. those that transmit various component colours equally. Frosted glass and red glass both have same transmittance factor of 70% [3] but they affect incident light differently, showing selective absorption. Refer table 1.

Table 1:
Typical transmittance data of different glass and plastic Material

Material	Approximate Transmittance (%)
Polished plate/float glass	80–90
Sheet glass	85–91
Heat-absorbing plate glass	70–80
Heat-absorbing sheet glass	70–85
Tinted polished plate	40–50
Figure glass	70–90
Corrugated glass	80–85
Glass block	60–80
Clear plastic sheet	80–92
Tinted plastic sheet	9–42
Colorless patterned plastic	80–90
White translucent plastic	10–80
Glass-fiber–reinforced plastic	5–80
Double glazed—two lights clear glass	77
Tinted plus clear	37–45
Reflective glass*	5–60

Similarly, the ratio of reflected light to incident light is called the "reflectance". Thus if half the amount of light incident on a surface is bounced back, the reflectance is 50% or 0.50, the remainder is absorbed or transmitted or both.

The amount of absorption or reflection depends upon the angle of light incident and the material. Refer fig 3, this effect is important when considering the penetration of sunlight into interior spaces and conversely the exterior glare produced by the reflection of the sun from building windows.

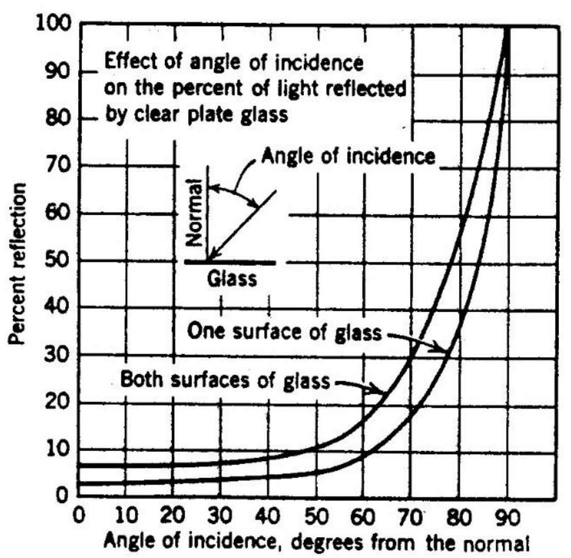

Fig3: Amount of absorption or reflection on the surface with the help of material used and the light incident.3.

3. LIGHT AND SIGHT

3.1The Human Eye

The human eye and camera operate on similar principles. Fig.4, the cornea acts as an outer refracting lens that introduces light in to the iris. The iris and pupil control the f-stop, or the opening of the eye & correspond roughly to a range of f 2.1 to f 11. The lens, which acts as a perfectly smooth automatic zoom lens, can focus from about 50 mm to infinity [7].

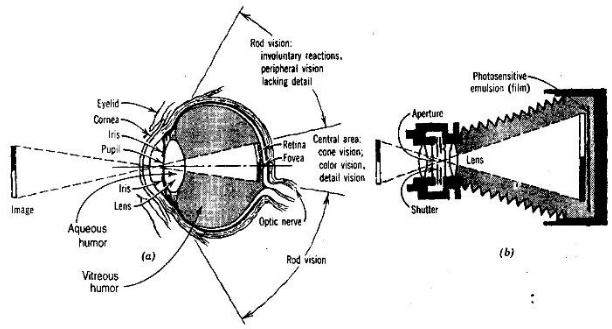

fig4: light is focused on retina, which contains approximately 150 million light sensitive cells.

3.2 Factors of visual acuity

The three components of the act of seeing are object or task, the lighting conditions and the observer [3]. Size of visual object is yet another important factor which comes in picture when we talk about visual acuity.

Visual acuity is generally proportional to the size of the object, given fixed brightness, contrast and exposure time. As we are focusing on the illuminance in commercial spaces which majorly covers the interiors and the different activities performed, it is important to know the appropriate illuminance levels for some of the important spaces which causes ease while designing. Refer table 2.

Table 2
Examples of activities/interiors appropriate for each maintained illuminance

Standard Maintained Illuminance (lux)	Characteristics of Activity/Interior	Representative Activities/Interiors
50	Interiors used rarely with visual tasks confined to movement and casual seeing without perception of detail	Cable tunnels, indoor storage tanks, walkways
100	Interiors used occasionally with visual tasks confined to movement and casual seeing calling for only limited perception of detail	Corridors, changing rooms, bulk stores, auditoria
150	Interiors used occasionally or with visual tasks not requiring perception of detail but involving some risk to people, plant, or product	Loading bays, medical stores, plant rooms
200	Interiors occupied for long periods or for visual tasks requiring some perception of detail	Foyers and entrances, monitoring automatic processes, casting concrete, turbine halls, dining rooms

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Table 2 contd.

300[a]	Interiors occupied for long periods, or when visual tasks are moderately easy [i.e., large details (>10 min arc) and/or high contrast]	Libraries, sports and assembly halls, teaching spaces, lecture theaters, packing
500[a]	Visual tasks moderately difficult [i.e., details to be seen are of moderate size (5–10 min arc) and may be of low contrast]; also, color judgement may be required	General offices, engine assembly, painting and spraying, kitchens, laboratories, retail shops
750[a]	Visual tasks difficult [i.e., details to be seen are small (3–5 min arc) and of low contrast]; also, good color judgements or the creation of a well-lit, inviting interior may be required	Drawing offices, ceramic decoration, meat inspection, chain stores
1000[a]	Visual tasks very difficult [i.e., details to be seen are very small (2–3 min arc) and can be of very low contrast]; also, accurate color judgements or the creation of a well-lit, inviting interior may be reauired	General inspection, electronic assembly, gauge and tool rooms, retouching paintwork, cabinet making, supermarkets
1500[a]	Visual tasks extremely difficult [i.e., details to be seen are extremely small (1–2 min arc) and of low contrast]; optical aids and local lighting may be of advantage	Fine work and inspection, hand tailoring, precision assembly
2000[a]	Visual tasks exceptionally difficult [i.e., details to be seen exceptionally small (<1 min arc) with very low contrasts]; optical aids and local lighting will be of advantage	Assembly of minute mechanisms, finished fabric inspection

For designer, selection and placement of luminaries, increased use of indirect lighting and particular attention to the spectrum of light sources are important. These requirements are mutually incompatible and difficult to respond to [2]. In work areas of this type, it may be wise to provide for the possibility of readily changing lighting conditions in a limited area to accommodate older individuals rather than attempt an overall design.

4. QUALITY OF LIGHT

4.1 Considerations of lighting quality

Quality of lighting is not related to quantity of illumination [3] which means quality is independent of amount of light present in the space.
In other words illumination should not be harmful to the viewers or the occupants. It should be glare free, shadow less and contrast free. Hard and long shadows can be avoided by designing the source of the light penetration into the space and also focusing on its position.

4.2 Glare and glare zones

Excessive luminances or excessive luminance ratios in the field of vision are called glare. Visual comfort means absence of glare.
When glare is caused by a light source in the field of vision, it is known as direct or discomfort glare. When glare is caused by reflections of light source in the in the viewed surface, it is known as reflected glare or veiling reflections. refer fig 5.

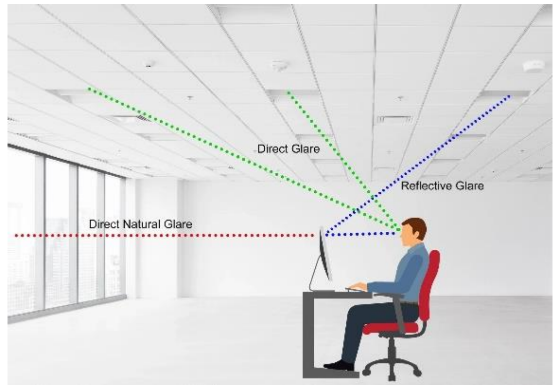

fig 5: explains the sources of glare

Glare zones: the direct and reflected glare light paths are delineated on the fig 6. Direct glare presupposes a head-up position, whereas reflected glare assumes eyes down at a reading angle. Factors that affect severity of the glare are: adaption level of the eyes, the apprehended size of the glare source, luminance ratios, room size and room finishes, size and position of lighting fixtures and windows [2].

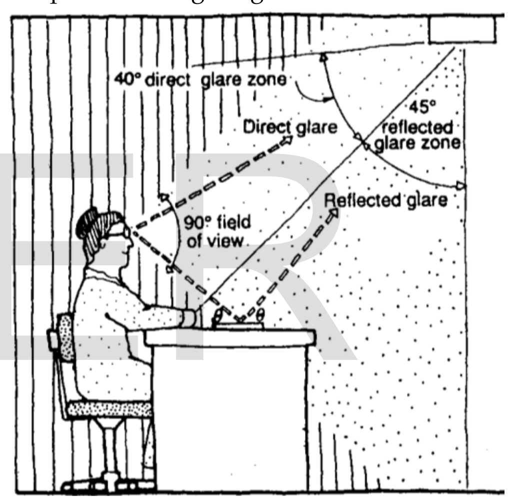

fig 6: indicating glare zones

Glare decreases rapidly as the brightness source is moved away from the direct line of vision, thus glare produced depends on the source's position in the field of view [2].

As we are looking into the lighting as a major part of the study these were some of the major criteria which are to be considered when we talk about the subject. With this it would be simple to understand designing daylighting or natural lighting inside the space

5. DAYLIGHTING AS A LIGHTING DESIGN FACTOR

5.1 Natural lighting and CRI

The term natural lighting is one that is thrown around quite loosely these days in the lighting industry [8]. Very simply put, a lighting source that closely replicates natural sunlight can be considered a natural light source. Sunlight in its pure form has a kelvin temperature of around 5,000 degrees kelvin and a colour rendering index of 100 [8]. As sunlight comes into contact with the earth's atmosphere and is reflected and refracted by water and dust particles the colour temperature actually changes throughout the day ranging anywhere from 5,000 to 6,000 kelvin [8] depending on the time of day and the amount of clouds in the sky. Artificial lighting sources within this range can appropriately be considered a natural lighting lamp as long as the colour rendering index is above 90.

The colour rendering index or CRI is a method for describing the effect of a light source on the colour appearance of objects, compared to a reference source of the same colour temperature. It serves as a quality distinction between light sources emitting light of the same colour. The higher the CRI of lamps with colour temperatures of 5,000-6,000 the better objects appear compared to outdoors [8].

Unfortunately in today's competitive marketplace some companies have taken to making up their own definitions of what natural lighting is [8]. A lamp with a colour temperature of 6,500 kelvin and a CRI of 82-84 is simply not a natural lighting source.

Daylight is indeed an amenity. Windows provide visual contact with the outside and the resultant daylight provides a bright, pleasant, airy ambience.

5.2 Traditional techniques to improve natural lighting

There are numerous ways that sunlight can be used advantageously inside buildings. The art and science of day lighting is not so much how to provide it but how to avoid the attendant undesirable effects [3].

Some traditional techniques to improve natural lighting in buildings are listed below.

5.2.1 Windows and skylights

The strategic installation of skylights, such as the ones shown in fig 7 allows natural light to enter a building through the ceiling. These can be especially useful in providing light when the Sun is high in the sky. In addition, the installation of tall windows allows outside light to easily enter rooms. As mentioned earlier the placement of these windows must be carefully considered to minimize potential glare. Solar shading devices known as overhangs, ref fig 8 can be used to minimize the direct Sun that enters the space.

fig 7: skylight in commercial space

fig 8: design of overhangs scatters the light entering the space in a better way and provides glare free space

5.2.2 Building design and orientation

There are numerous design changes that can be made on buildings to increase the amount of natural light that can enter the building. One way to improve the amount of natural light in a building is to build with a shallow-plan design. This simply means buildings are designed so that daylight can enter all rooms and hallways, the building is shallow enough that light can penetrate all the way in [3]. The installation of task lighting (lighting directly over work spaces) can also help reduce energy costs as it reduces the need to light the entire room [3].

Since daylighting components are normally integrated with the original building design, it may not be possible to consider them for a retrofit project. [7]

If possible, the building footprint should be optimized for daylighting. This is only possible for new construction projects and does not apply to retrofits. If the project allows, consider a building footprint that maximizes south and north exposures, and minimizes east and west exposures. A floor depth of no more than 60 ft., 0 in. from south to north [7] has been shown to be viable for daylighting. A maximum facade facing due south is the optimal orientation. Deviation from due south should not exceed 15° in either direction for best solar access and ease of control refer fig 9.

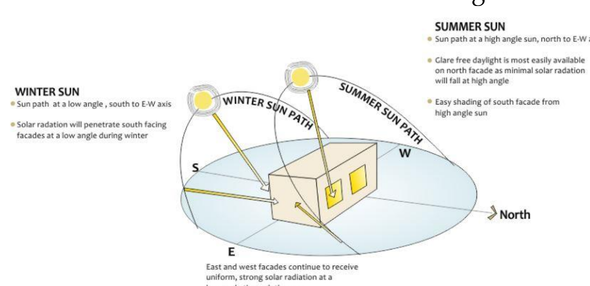

fig 9: orientation of building to get maximum sunlight during different seasons

With the building sited properly, the next consideration is to develop a climate-responsive window-to-wall area ratio. As even high-performance glazings do not have insulation ratings close to those of wall constructions, the window area needs to be a careful balance between admission of daylight and thermal issues such as wintertime heat loss and summertime heat gain. The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) offers [9] guidance on these ratios per climate zone in their Standard 90.1 energy code, but these are primarily minimal for thermal performance and do not consider admission of daylight.

A high-performance glazing system will generally admit more light and less heat than a typical window, allowing for daylighting without negatively impacting the building cooling load in the summer. This is typically achieved through spectrally-selective films. These glazings are typically configured as a double pane insulated glazing unit, with two 0.25 in. (6 mm) thick panes of glass that are separated by a 0.50 in. (12 mm) air gap [9]. This construction gives the insulated glazing unit a relatively high insulation rating, or R-value, as compared to single pane glass. A low-emissivity coating is also often part of these high-performance glazing units, which further improves the R-value of the unit. [9]

5.2.3 Light tubes and fiber optics

There are also a number of more experimental techniques being used in an attempt to direct light into buildings. One of these methods is by using steerable mirrors to direct light into areas it would not normally reach. [3] As well, the use of optical fibres and light ducts to spread natural light through a building is currently being experimented with. Light ducts are simply tubular devices that are coated with a reflective film that channel light from the roof of a building to the interior ceiling. [3] They are beneficial as they are much smaller than skylights, but just as effective. Fibre optic lighting devices send light through a bundle of optical cables into a building using a physical mechanism known as total internal reflection. This simply means that the light in the cables bounces around on the inside of the cable, being transported as it reflects. Refer fig 10.

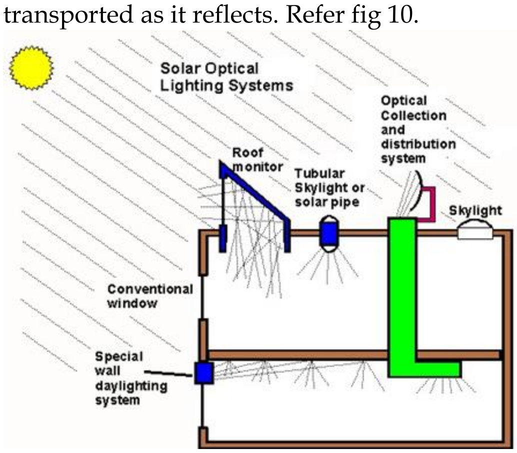

fig 10: indicating the tubular lightpipe system

6. INNOVATIONS IN COMMERCIAL DAYLIGHTING

With all the existing techniques of getting natural lighting inside the space there are few innovations in this field which can help in achieving better results.

6.1 Daylight harvesting

Lights affect the way we feel. It's obvious that the natural light is a source of illumination. With ever-increasing demands for energy savings on one side and better recognizing the benefits of natural light for our health on the other side, more businesses are turning to daylight harvesting as means to conserve energy and bring sunlight back into their buildings and workspaces. [10]

Daylight Harvesting is one of the most advanced techniques used in sustainable lighting designs for contemporary buildings. It automatically dims or adjusts the brightness of light in response to the amount of natural light available in a space. Utilizing natural daylight coming through the windows or skylights minimizes the amount of energy used in artificial lighting. [10].

The daylight harvesting system employs light sensors, also known as photocell sensors, to detect the prevailing light level in the environment. It then sends the intensity of light received to a controller, which is connected to the lighting control system. The control system in turn adjusts the electric lights automatically according to the measured light level. Product simulations have shown these commercial dome skylights harvest up to 56 more minutes of additional sunlight per day, for a potential yearly lighting savings of up to 340 hours. [4]

6.1.1Types of daylight harvesting system

There are two control modes for daylight harvesting; open-loop and closed-loop control systems.

In an open-loop control system, the photo sensor measures only the intensity of natural light, thereby adjusting the intensity level of the artificial light to support, offset, or balance the contribution of natural light during the day.

Open-loop sensors are typically installed outside the building or near a window or facing towards the source of daylight. [5] Since there is no feedback from the electric lighting, this is considered an open-loop.

In a closed-loop control system, the photo sensor detects the total amount of light intensity, from both natural and electric sources in the environment. [5] And, based on the detected light intensity level, it adjusts the intensity level of the artificial light to maintain pre-set ambient light intensities.

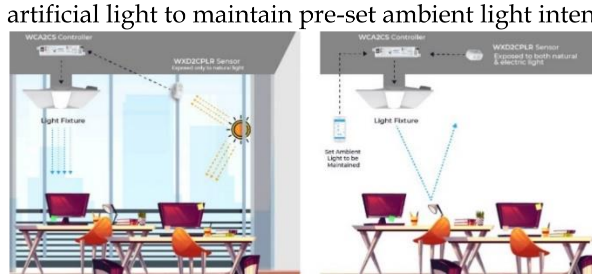

fig 11: Indicates open and closed loop system.

Closed-loop sensors are typically installed indoors, facing away from the daylight source.

Since the photo sensor measures the artificial lighting system's output, it provides feedback to controller and make further adjustments to maintain the pre-set value creating a closed loop. Refer fig 11.

6.1.2 Advantages of the system

Energy Savings: It increases energy savings by dimming or turning off lights based on the natural daylight entering the space.

Provides Comfort and Convenience: It helps to maintain proper light intensity in a space by continuously and automatically adjusting lights.

Healthier Working Conditions: Providing right amounts of light to employees helps in maintaining proper circadian rhythms that are crucial to good health and adequate sleep besides preventing seasonal affective disorders. Letting in natural light to workplaces provide better concentration, creates a positive mood, and drive healthier employee life.

Meet Codes and Standards: Daylight harvesting helps meet Title 24 and ASHRAE 90.1 requirements using continuous dimming, task tuning, space control, and automatic/manual ON/OFF controls. It achieves the mandatory compliance needs set for building construction.

6.2 Advanced glazing

Traditionally, windows have been produced from clear glass. This is ideal for light transmission but also enables a large amount of heat transmission and thus has a high impact on the energy demands of a building. Consequently, various glazing developments have been made to reduce the heat transmission of glazing. There is no single glazing type which will be suitable for all applications, so here are some of the options, some of which are already on the market, others which will take a few more years to be commercially available. In many cases a combination of the technologies can be applied to give the optimum solution.

a. Electro chromic Glass (or smart glass): that electronically tints glass to switch from clear to dark with the click of a button. An electronically tintable glass that can be switched from clear to a dark tint at the click of a button, or programmed to respond to changing sunlight and heat conditions. Energy consumption and costs are greatly reduced. Electro chromic glass offers significant advantages over conventionally glazed products because they provide the highest possible solar control without sacrificing the view through the glass.

b. Photovoltaic glass: Skylights are an ideal application for photovoltaic glass (PV). They are normally well exposed to the sunlight, allowing for optimal energy yield. PV skylights also improve thermal inner comfort, since most of the UV and infrared radiation are filtered out by the Silicon-based material. Semi-transparent PV glass reduces the need for artificial lighting, generates power, and provides thermal and sound insulation.

c. Translucent insulated glass: Used in architectural daylighting to provide the highest quality of diffused daylight, it converts harsh direct beam sunlight
into soft diffuse daylight while allowing you to design your desired light level without excessive heat gain, glare, or fading. Filling with Aerogel improves energy efficiency and reduces sound transmission.

d. High performance glass: High performance Low-E insulated glass options are available as an economical alternative to our other energy efficient Advanced Glazings. These triple silver coated options are engineered to provide high visible light transmittance while controlling solar heat gain, essential for minimizing cooling costs.

e. Multiwall polycarbonate: High-performance, lightweight panels maintain high clarity and provides an outstanding balance of impact strength and stiffness, excellent thermal insulation, UV protection, flame and condensation control, and long-term high light transmission. Panels filled with Lumira aerogel offer superior thermal performance of a typical insulated glass skylight, full spectrum diffused daylight, completely moisture resistance, and reduced sound transmission.

By incorporating innovations in daylighting design, the built-environment can become more sustainable through technology and automation for a healthier, happier place to learn, work and recover.

7. BENEFITS OF INCORPORATING DAYLIGHTING IN COMMERCIAL SPACES

To get the daylighting right on a project, the design needs to go way beyond the window design. Daylighting isn't just focused on glazing but the whole integrated design concept that involves the building's climate, orientation, floor plan and the lighting design. Daylighting needs to be considered at the start of a project to ensure it works effortlessly with the wider architectural design.

Whether the design concept is aiming to reduce energy usage, improve internal environments of the occupants or generate more LEED points, maximising natural light within commercial buildings is an important part of good design. The strategic placement of glazing to maximise the influx of natural light has been shown to improve productivity, reduce absenteeism and improve general well-being.

With this some of the major benefits are as follows;

Energy efficient: The benefits of daylighting can be extensive, mainly because electric lighting accounts for anywhere between 35% to 50% of electrical energy consumption in commercial spaces. [3] In the summertime the heat created by electric lights can cause the building to overheat. Thus, using daylighting techniques can reduce the energy used to cool these buildings by 10-20%.[3] For some commercial buildings, total energy costs can be reduced by as much as 1/3 through strategic use of daylighting technologies.[3] In addition to saving money, reducing the amount of electrical energy used also reduces the amount of greenhouse gases released that are associated with the production of said energy.

Lively environment: Research has shown that natural light helps in boosting the mood and productivity level of the people. With the decent supply of daylight, you can make your employees happy, calm and health which will eventually improve their productivity.

Good for eyesight: As compared to the artificial lighting sources, natural light reduces the level of eye strain which is very beneficial for people who are working in the offices.

Keeps the place healthy: One of the awesome benefits of daylight is that it reduces the amount of moisture at your workplace and keeps it healthier for your employees. If you let sunlight enter your office, then this will automatically solve the problem of musty indoor air.

Aesthetic appearance: Interior designers and architects use natural lighting to make space look larger by illuminating the interior structure. The sunlight helps in increasing the aesthetic appearance of the space as well.

8. CONCLUSION

When designing buildings, emphasis is placed on construction and maintenance costs. However, real people will be utilizing these buildings, so consideration should be given to their psychological and physiological well-being. With properly installed and maintained daylighting systems, natural light has proved to be beneficial for the health, productivity, and safety of building occupants. Natural light helps maintain good health and can cure some medical ailments. The pleasant environment created by natural light decreases stress levels.

Daylighting is one of the fundamental need of building structures, even building are mounted with glazing materials and windows daylighting in interiors are not getting better efficiencies in visualization. Daylighting not only concern lighting in the building but also a sustainable energy efficient discipline of architecture. Conventionally industrial buildings are mounted with side and rooftop windows for adequate daylighting and thermal comfort into the building. Depending on the certain climate condition, it is evident daylight will depend on the glazing control and illuminance level. For the improvement of effective daylighting in industries, proper measures of building orientation, climate, type of glazing and usage of artificial lighting is required.

This paper studies the various aspects and importance of daylighting in commercial building and also states the guidelines need to be considered while designing the space for optimum natural lighting. It also focuses on energy consumption load and the amount of energy used for active lighting for a commercial space which leads to heavy finance expenditure as well. Natural lighting contributes in various phenomena's to improvise on occupants well-being as well as reduce the energy consumption load. The important factor which one needs to consider with lighting is that, lighting should be considered at the very first step of planning, the execution of the building should go hand in hand with respect to lighting as a major design factor to get maximum benefits of this natural energy source available. The result of this study shows that if the usage of artificial lighting is reduced to minimum and with different techniques studied natural lighting will be incorporated in the commercial spaces it can save up to 30% of its energy and also promote sustainability.

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