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ASPECTS AND ISSUES OF DAYLIGHT PERFORMANCE IN OFFICES: A REVIEW STUDY

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ABSTRACT

Proper Daylight Availability inside offices can significantly help in improving the performance of officials and reducing the energy load on artificial sources. This paper aims to review the factors lying inside or outside of the office that affect daylight availability inside the working area. Existing regulations for daylight availability are also discussed in this paper with the methods available for calculating daylight availability. To maintain visual comfort inside offices glare is one of the major issues which is required to address with the enhancement of daylight availability. A review of the literature regarding glare and the ways to control glare is also discussed in this paper.

Introduction

The visible portion of solar radiation is known as daylight [1]. Daylight is a never-ending source of light which is a subject of interest for architects because of its ability to change the psychological parameters of building interiors[2]. Buildings should utilize daylight as much as possible because it provides amenity and aesthetic value. Daylight reduces electricity consumption by reducing the load on artificial lighting[3]. Daylight enhancement is usually considered to be a part of energy conservation but daylight affects human health in several ways including psychology, mood, etc. The person working in proper natural light feels happy and cheerful. Nowadays in the interest of daylight and energy efficiency, the design solutions for better daylight integration are coming into existence[4]. The relationship between the indoor environment and human nature is of vital importance and can be easily understood by increasing stress in coming generations[5]. This relationship may not be easy to find and lack of proper daylight exposure will result in numerous diseases by pathogenic viruses. Research on psychology relating to the effects of working in the absence of daylighting found that it will result in problems like anxiety, eating disorders, and chronic tension[6]. In general, Daylight is measured by the daylight factor which is the ratio of light level inside the structure to light level outside the structure, the daylight factor must to be between in the range of 2–5%[3]. Leslie Philip shows the evolution of daylight in different civilizations wherein Egyptian civilization the clerestory openings provided for daylight. Greek openings were oriented toward the east for better daylight during the morning to lighten up the statues in their temples. Romans developed bigger openings and tried to eliminate columns for passive solar heating and daylight enhancement[7]. Mohamed Boubekri explained the role of the sun in the past when the people of Egypt considered the sun as a divine father and supreme ruler of all creations. During the Industrial Revolution, the sudden growth of poor habitable spaces resulted in diseases like cholera, typhus, etc which in return grabbed the attention of designers related to the need for daylight. Different planning concepts were proposed during this time to provide plenty of space

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required for daylight and ventilation[6]. Due to cheap energy, availability of fluorescent lights, and air conditioning during the 20th century, the importance of daylight was ignored which was recalled in 1970 because of the oil crisis. Nowadays in the interest of daylight and energy efficiency, the design solutions for better daylight integration are coming into existence[8]. In offices, the integration of daylight must be well designed to manage the constant light levels on the working table[9]. The visual discomfort due to the change in the lighting environment leads to a psychological disorder which in return makes the worker conscious of the change in the physical environment. So it is necessary to maintain the relationship between the worker and the physical environment[10]. While the fixed desk remains a central part of office life, tablet, and touchscreen computers are now commonplace and allow those occupying office space to move around, effectively carrying their workspace to wherever they need to be or feel comfortable working. The need to accommodate this flexibility has brought significant challenges to managing daylight inside offices[11]. Eliyahu and Glenn surveyed in January 1983 in the Wainwright office building in St. Louis, Missouri on daylighting issues in the workspace environment with a Questionnaire based on 24 workspace features. Luminance levels on the workstation were also recorded and found to be between 320lux to 650lux. Most workers were found satisfied with the conditions of their work environments[12]. Jean conducted the research that factors like work-space design, the condition of the ambient environment, lighting, and visual and acoustical privacy are important for workers' satisfaction and productivity[3] Literature

To find out the factors affecting daylight availability literature is reviewed showing the relations of different building factors with daylight.

2.1 Study on Internal Factors Affecting Daylight Availability.

The internal factors affecting daylight availability are listed in Table 1:

Table 1: Internal Factors Affecting Daylight Availability.

S.no		Factors	Authors	Year	Type of Effect	Optimum configuration
1	Room Geometry	Room Width	[Deng X, Wang M]	2022	Mixed	Room width influences daylight performance. An optimal window width coefficient of around 0.7 enhances glare control in perimeter areas. [13]
		Room Depth	[S. Cammarano, A. Pellegrino] [M. Boubekri] [A. Das and S. K. Paul]	2015 2014 2015	Negative	The daylight availability decreases with the increase of room depth[14][15][16].

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		Room Height	[Deng X, Wang M]	2022	Mixed	Moderate room heights of 3.3~3.6 m are recommended for balanced daylight quality in contemporary reading spaces.[17]
2	Internal surface reflectance	Wall Reflection	S. Simm and D. Coley [R. A. Mangkuto, M. Rohmah, and A. D. Asri] [I. Acosta, C. Varela, J. F. Molina, J. Navarro, and J. J. Sendra] [A. Das and S. K. Pau] [A. H. Sherif, H. M. Sabry, and M. I. Gadelhak]	2011 2016 2018 2015 2012	Positive	Interior surfaces with better wall reflectance will result in more daylight availability. In small rooms, the daylight availability is more as compared to large rooms[18][19][20][16][21].
		Ceiling Reflection	[Katunský D, Dolníková E]	2022	Mixed	White, gray, green, or yellow walls with a white ceiling are recommended for optimal reflection.[22]
		Floor reflection	[Andrea Coelho Laranja]	2016	Mixed	Different reflective surfaces contribute variably to illuminance levels

2.1.1 Room Geometry

Reinhart describes the influence of various design variables on the daylight availability in open-plan office spaces using the RADIANCE-based annual daylight simulation method DAYSIM. 1000 office settings have been investigated with varying workstation sizes with a range of 10x10 ft2, 8x8 ft2, and 6x6 ft2 in an open-plan office. It is found that the workstations that are near to façade have no effect of size on daylight availability but as the distance from the façade increases the daylight availability increases with the increase of workstation size[23].

Silvia Cammarano and Anna Pellegrino investigated that an increase in room depth will result in a

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decrease in daylight availability. 30 % less daylight will be available when the room depth is increased by 3 to 4.5m or 4.5 to 6 m whereas in case of a room depth of more than 6 m the daylight availability will effect by 18 %[14]. Boubekri found that the illuminance level of daylight beyond 3 meters from the side window starts to drop[15]. With the increase of room depth, the daylight factor will decrease resulting in a decrease in daylight level[16].

2.1.2 Interior surface reflectance

Simm and Coley conduct research on the relationship between wall surface reflectance and daylight availability. They found that by the change of reflectance in small rooms the daylight availability will be affected significantly whereas in a larger room, the effect is minimal [18]. A wall reflectance of 0.8 is optimum for daylight availability on the basis of different performance metrices[19]. Acosta and Varela proposed an accurate method for calculating the daylight factor which is based on internal surface reflectance. Scaled model and real courtyard measurements are used to define daylight factor where black, grey, and white walls are used for different internal reflectance[20]. Use of white paint inside the room can increase internal reflectance by 300 lux to 650 lux[16]. Ahmed H. Sheriff has studied the effect of solar screen rotation on daylighting by axially rotating solar screen at three different angles with 10-degree increments. It was also found that daylight availability distribution at the far end can be improved by increasing the reflectivity of internal surfaces[21].

2.2 Study on Factors of Fenestration Affecting Daylight Availability.

The factors of fenestration affecting daylight availability are listed below:

Table 2: Factors of fenestration affecting daylight availability

S.no	Factors	Authors	Year	Type of Effect	Optimum configuration
1	Window area	[I. Acosta, C. Munoz, M. A. Campano, and J. Navarro] [M. Boubekri and L. L. Boyer] [N. D. Dahlan, P. J. Jones, D. K. Alexander, E. Salleh, and J. Alias] [M. Bodart and A. De	2015 1992 2009 2002	Positive	With the increase of window area daylight availability will increase[24][25][26][27].

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		Herde]			
2	Visual light transmittance	[D. H. W. L. Ã and E. K. W. Tsang] [P. Xue, C. M. Mak, and H. D. Cheung] [D. Phillips] [N. Ibrahim and a. Zain-Ahmed] [D. H. W. L. Ã and E. K. W. Tsang] [S. G. Colaco, C. P. Kurian, V. I. George, and A. M. Colaco]	2004 2014 2004 2007 2008 2008	Positive	Visual light transmittance of clear glass is around 0.88 and it is the best glass in the manner of daylight availability if we don't consider glare[28][29]. Clear glass is best for daylight availability whereas tinted glass performs according to the level of tint. Electrochromic, photochromatic, etc are the glazing's can be used for qualitative daylight availability.
3	Wall Window Ratio	[R. A. Mangkuto, M. Rohmah, and A. D. Asri] [S. Cammarano, A. Pellegrino, V. R. M. Lo Verso, and C. Aghemo] [H. Voll and E. Seinre] [D. H. W. L. Ã and E. K. W. Tsang]	2016 2015 2014 2008 2016 2007	Positive	Optimum WWR varies with the type of glass used. In the case of clear glass, 30% is found optimum and the relation of WWR with daylight availability significantly decreases as the Wall window ratio increases[19][14][30][28][31][32].

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		[F. Goia] [N. Ibrahim and a. Zain-Ahmed]			
4	Window Position	[I. Acosta, C. Munoz, M. A. Campano, and J. Navarro]	2015	Mixed	Positioning the window on the upper side of the wall will result in more daylight availability[24].
5	Number of Windows	[Voll H, Seinre E] [Zomorodian Z, Korsavi S]	2014 2016	Mixed	Increasing the number of windows affects daylight availability and heating/cooling loads in offices.[33] Increasing window number and size enhances daylight performance in classrooms.[34]
6	Window Shape	[Farivar S, Teimourtash S]	2023	Mixed	Window shape impacts dynamic daylight performance in office buildings. Square windows positioned centrally achieve optimal spatial daylight autonomy.[35]
7	Shading Type	[D. H. W. L. Ã and E. K. W. Tsang] [N. Ibrahim and a. Zain-Ahmed]	2008 2007	Mixed	Shading devices are a better option for even distribution of daylight[28][32].

.2.1 Window area

The square window is 5% to 15% more efficient in producing daylight factors as compared to the horizontal window on the central axis. The difference increases at the farthest point to the window. In larger windows, more light is scattered near the window whereas at the distance equal to the height of the room the daylight factor tends to be directly proportional to the glass surface[24]. Conducting a statistical test using regression analysis Boubekrit shows the variation of 29.9% in perceived glare by a change in window size. The prediction curve shows a bell shape where maximum glare is received on average window sizes[25]. N.D Dahlan has studied the influence of window size on the visual comfort of the occupants and suggested that external illumination being the variable factor affects the comfort more than static window size[26]. Bodart and Herde found that for larger windows the requirement of 500 lux is easy to obtain[27].

2.2.2 Visual light transmittance

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Examining 35 buildings in Hong Kong it was found that the VT of clear glass is 0.88 but it allows a large amount of solar heat to pass. Visual Transmittance of tinted glazing is ranging between 0.23 to 0.51 and VT of reflective glass is 0.12[28]. Xue and Mak found that Visual transmittance of the glazing type was positively correlated with light level, glare (comfort), naturalness, beauty and pleasantness, and precision. Visual transmittance and glare are in a negative correlation[29].

2.2.3 Wall Window Ratio

WWR of 30% is found to be optimum for daylight availability by the evaluation of six different matrices[19]. The daylight availability will increase to 61 % on an increase of WWR from 0.3 to 0.4 whereas in case of an increase from 0.4 to 0.5, the daylight availability will increase up to 30%[14]. Hendrik shows the daylight availability inside the office based on window design parameters. The window shares of 25 – 35% fulfill the daylight availability[30]. Examining different buildings in Hong Kong Danny found that the percentage of WWR for Low-E glass, reflective glass, tinted glass, and clear glass is 46.5%,44%,42 and 36.4%[28]. Francesco Gioia has proposed the optimal window-to-wall ratio for office buildings. The optimal WWR value is one that measures on an annual basis the sum of the energy used for heating, cooling, and lightning. Most of the optimal WWR values are found in the relatively narrow range of 0.30<WWR<0.45. The south-facing façade shows a larger variability as high as 0.60 in cold and 0.20 in very warm climates. This analysis shows out that warm climates are those where the choice of a suitable WWR value is more critical. The total energy use may increase in the range of 5-25% when the worst WWR configuration is adopted[31]. Ibrahim and Ahmed found the optimum WWR to achieve the maximum percentage of daylit floor area for a 4.5m deep room are 40%, 55%, and 65% for clear, tinted, and reflective glass, respectively[32].

2.2.4 Window Positioning

Top positioned windows gain 20% more daylight factor as compared to the centralized window, whereas opening in the center of the window will result in far more light[24].

2.2.5 Number of Windows

Wall demonstrated that increasing the number of windows affects daylight availability and heating/cooling loads in offices.[33] Zomorodian shows increasing window number and size enhance daylight performance in classrooms.[34]

2.2.6 Shape of window

Fariver shows that window shape impacts dynamic daylight performance in office buildings. Square windows positioned centrally achieve optimal spatial daylight autonomy

2.2.7 Shading Type

Danny and Ernest examined the shading types of 35 buildings in Hong Kong and found that the buildings constructed in the 60s to 80s had overhangs and side fines with clear glass. In buildings from 80 to 90s due to the use of curtain walling, the shading devices were neglected. In the latest buildings, metal overhangs are employed to meet the heat gain standard of 30Wm-2 in Hong Kong[28]. External shades were able to reduce the DF value near window areas and provide a more even DF distribution indoors [32].

2.3 Study on External Factors Affecting Daylight Availability.

The factors of fenestration affecting daylight availability are listed in Table 3:

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Table 3

S.no	Factors	Authors	Year	Type of Effect	Optimum configuration
1	Orientation	[R. A. Mangkuto, M. Rohmah, and A. D. Asri.] [S. Cammarano, A. Pellegrino] [M.-C. Dubois and Å. Blomsterberg]	2016 2015 2011	Mixed	The best orientation for maximum daylight availability is in the South direction[14] [19] [36].
2	Tree Geometry	[Balakrishnan P, Jakubiec J]	2023	Negative	Trees affect daylight inside and outside buildings by attenuating, scattering, and transmitting light.[37]
3	External Obstruction	[C. Schittich] [I. A. Mashaly, Y. M. Rashed, M. Adel, and K. Nassar] [D. H. W. Li, S. L. Wong, C. L. Tsang, and G. H. W. Cheung] [P. Xue, C. M. Mak, and H. D. Cheung]	2003 2015 2006 2014	Negative	External obstructions prevent the daylight from getting inside which will result in poor daylight performance[38][39][40][29].

2.2.1 Orientation

Mangkuto and Rohmah undergo a simulation study to investigate window orientation using six types of daylight metrics in tropical climates. The south orientation of the window is found to be an optimum solution for daylight availability[19]. Around 65.7% of daylight is available in South-facing rooms whereas in a west-facing room daylight availability is around 57.7 % and in north-facing rooms it is 50.6%[14]. Daylight availability in the north-oriented rooms is less as compared to the south, east, and west[36].

2.3.1 Tree Geometry

Balakrishnan shows the effect of trees on daylight inside and outside buildings by attenuating,

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scattering, and transmitting light.[37]

2.3.3 External Obstruction

Muller and Schuster concluded that daylight availability inside buildings reduces with the increase of external obstructions like large trees around the building[38]. Mashaly undergoes a parametric study for external obstruction. Trees are simulated in radiance with some defined parameters like tree leaves, density of leaves, and tree size. The round trees are more favorable than square trees for simple south-facing rectangular windows [39]. Wong and Tsang found that to meet the recommended average DF, the angle of obstruction should not be less than 10 degrees for the kitchen and between 25 degrees and 45 degrees for the bedrooms[40]. External obstruction is the major physical factor affecting luminous Comfort in buildings[29].

3. Methods for finding the relation between factors.

3.1 ANN

Beccali and Bonomolo developed a daylight-linked control systems for indoor illuminance assessment using Artificial Neural Networks. The configuration of sensors and optimum settings are also achieved by Artificial neural networks[41]. Naydin and Binol predicted daylight illuminance in office buildings by the use of artificial neural networks. Illuminance data were collected for 3 months by applying a field measuring method. Utilizing weather data from the local weather station and building parameters from the architectural drawings, a three-layer ANN model of feed-forward type (with one output node) was constructed[42].

3.2 Fuzzy Logic Model

Kazanasmaz classifies the effectiveness of daylighting in an office with a movable blind system by use of the fuzzy logic model. All measurements of daylight illuminance were conducted at 15 reference points by following certain practical guidance offered by the Chartered Institution of Building Services Engineers. The input parameters of the fuzzy model were hour, angle, distance, and point location, which may be easily employed and examined in early architectural design schemes[43].

3.3 Sensitivity analysis

Sensitivity analysis in Mendelian randomization assesses how unmeasured confounding impacts causal inference, emphasizing fixing observable parameters to determine the robustness of causal direction inference. Sensitivity analysis assesses the impact of missing outcome data on mean and proportion estimates, considering missingness mechanisms like completely at random, at random given observed data, or not at random.[44]

4 Daylight calculation

Chel A and Tiwari G proposed a new modified daylight factor model that incorporates time variation concerning zenith angle and vertical height (h) of the working surface[45]. By use of theoretical calculations, scale model measurements, and radiance calculations the daylight levels on rooms and walls of the atrium are derived by Du J, Sharples S[46]. Horizontal Global and diffuse components are mainly recorded for calculating solar irradiance[47]. International Daylighting measurement program which is categorized into two categories general class and research class calculates irradiance, illuminance, and sky luminous distribution. A luminous efficacy approach is carried out to investigate the efficiency of the horizontal daylighting system[47]. Chug developed different statistical models for

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determining the Luminous efficacy under different conditions of the sky[48]. Li and Lam state that Luminous efficacy can be made more energy efficient by the use of diffused illuminance[49]. Little Fair predicted the energy consumption for day lit by calculating internal Daylight distribution in a daylit building. Little Fair examined three procedures for calculating daylight distribution one is by multiplying the CIA factor with the factor analyzed by orientation and horizontal brightness. The second one is using Sky techniques and the third one uses vertical external illuminance data as a base[50].

4.1 Computer modeling

To calculate and judge the effectiveness of any daylighting design strategy, it is necessary to perform some form of modeling exercise. Simple hand calculations of average daylight factors to the fully rendered computer images of simulation programs can be used[3]. Wienold and Christofferson undergo computer simulation to find out daylight distribution and glare using RADIANCE and DAYSIM. Computer model simulation is performed for finding useful daylight illuminance, luminance ratios, and glare[51]. DOE-2.1E, a whole building simulation tool, is used to determine the effects of daylight on lighting electricity use as well as total electricity use for typical office buildings. Vera optimized fixed exterior complex fenestration systems component of offices located in Montreal (Canada), Boulder (USA), Miami (USA) and Santiago (Chile)[52]. Fusi and Budaiwi investigated the energy savings when daylight and artificial light are integrated while maintaining visual comfort. Design Builder software was used to carry out the energy and visual comfort analysis of a typical office building, because of its distinctive features that allow complex buildings to be modeled rapidly[53]. Shameria simulated 12 different models of double-skin façade simulation in different outdoor lux conditions for analyzing indoor lux The percentage of the office space covered with at least 200 lx are found in the range of 40–68%,13–52%, and 5–30% at an outdoor illuminance of (19,000, 12,000, and 6000) lux[54]. Taylor and Bannister found the impact of glazing selection on daylighting and energy performance for an office building in Canberra. A daylighting study was performed using ECOTECT. The study examines the daylight levels obtained using a variety of glazing types including clear glass that would give the highest level of natural light. There is a high variation of illumination near the windows. The results for other glazing types show areas of 2.5% as well as 1% daylight factors[55]. Bodart and Herde evaluated global energy saving in office buildings through the use of daylighting. Several façade configurations have been modeled, for the four main orientations and three combinations of internal wall reflection coefficients. These simulations were performed by coupling daylighting simulation tool (ADELINE) and a dynamic thermal simulation software (TRNSYS)[36]. The computer simulation tool, Energy Plus was used to model the daylighting performance of a high-rise residential building facing severe sky obstructions in Hong Kong[40].

4.2 Full-Scale Models

Daylighting performance for office buildings in Hong Kong is analyzed by full-scale modeling. The daylighting performance of office buildings is determined through a survey of 35 office blocks completed in different years. Five key building parameters affecting the day-lighting designs namely, building area and orientation, glazing type, shading devices, and color of external surface finishing were presented[56]. Using full-scale modeling the effect of the facade alternatives on daylight illuminance in offices is analyzed. Full-scale studies of three different offices are conducted to calculate values in terms of the required minimum illumination level for visual comfort and to determine suitable building

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envelope alternatives for projects with certain conditions of obstruction, window, and room properties[57].

4.3 Scaled Models

Scale model tests have often been used to predict the performance of daylighting systems and to evaluate the accuracy of the illuminance distribution, which can be estimated with relative ease by changing the physical conditions of the scale model. scale model allows the design team to evaluate both the quantitative and qualitative performance of a daylighting system during the design phases[48]. The simplest methods are sometimes the most effective, especially in the early stages. It is usually sufficient to construct a model no larger than a desktop. Surfaces should have the same reflectance and colors as in the completed space and should be viewed under lighting conditions similar to the intended site. This can be done in an artificial sky or under a real sky[3]. Keighley using a 1/12th scale model created variable geometry and window setting to find out the preferred setting for better daylight availability[58]. Aghemo and Pellegrino used scale models to measure the performance of different shading systems. Both winter and summer conditions all year round are taken into account for daylight variations[59]. Simulation runs were performed on a model that represents an office space - 4m wide, 4.5m deep and 4m ceiling height. The calculations were taken for different WWR, Glass types, and External Shades[32].

4.3 Field study

Participation of 235 office workers surveyed in high-rise buildings with glazed areas ranging from 11% to 68% of the office wall area. Wotton and Barkow examined the relationship between windows, lighting, work performance, workers' mental and physical well-being, and subjective perceptions in six Canadian office buildings[60]. Xue and Cheung conducted a questionnaire Survey to find out the effect of daylighting and human behavior on luminous comfort. 340 questionnaires were filled and analyzed by using SPSS 19.0. In analyzing the response statistics, the Chi-square test and stepwise regression were adopted to identify the effects of particular aspects of human behavior and daylighting quality[29].

5. Metrices for Daylight availability

5.1 Illuminance

Total luminous flux on a surface, per unit area is known as Illuminance and it can be measured for a point that is required to be lit by daylighting. It is measured in lux and 500 is found optimum for offices[61].

5.2 Daylight Factor

Natural source luminance is determined in the daylight factor which is the ratio of internal luminance to the external luminance with respect of the horizontal plane. Daylight factor is measured based on its three components which are the Sky component, internal reflective component, and external reflective component[50]. The average daylight factor is used to evaluate the daylight in a space. The average daylight factor must be at least 2% for space during the daytime. In case of less availability of artificial lighting, the average daylight factor must not be below 5%. In the case of offices, the range of average daylight factor must be between 2% - 5%. The daylight factor defines a constant relationship of the daylight available at an unobstructed place outside, which is received at a point inside a space [3].

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As per Lighting Guide LG10, the main factors affecting daylight availability inside an office are site characteristics and window size [1]. Daylight is a never-ending source of light which is a subject of interest for architects because of its ability to change the psychological parameters of building interiors[2]. Buildings should utilize daylight as much as possible because it provides amenity and aesthetic value. Daylight reduces electricity consumption by reducing the load on artificial lighting[3]. The daily. Trezenga and Loe found that for DF more than 5% of the room appearance will be bright day lit. DF between 2-5% will have day day-lit appearance but electric light is usually required. For DF below 2% appearance is under-lit and electric day lighting is used[62].

5.3 *Useful Daylight Illuminance*

Nabil and Mardaljevic found the illuminance less than 100 lux short of the useful range and more than 2000 lux exceeded than useful range[63].

5.4 Continuous Daylight Autonomy

Rogers and Goldman found that the daylight below daylight illuminance is partially contributing to illuminating and is helpful if perceived linearly[64].

5.5 Daylight Autonomy (DA)

Reinhart proposed these metrics which define the daylight availability based on occupied hours met by the minimum daylight threshold in the whole year[65].

5.6 Spatial Daylight Autonomy (sDA)

This metric defines daylight availability based on specified fraction of occupied hours met by the minimum daylight threshold in the whole year[66].

6. Visual Comfort

In addition to thermal performance and solar control, objectives for fenestration design are increasingly driven by visual comfort, view, daylight sufficiency, and the quality of interior daylight distribution[67]. Lason and Athanasios used the triple visual environment criterion for holistic evaluation of the visual environment in offices. Three parameters for evaluation include Visual Comfort Autonomy (VCA) which is defined as the portion of working hours when a person in a specific position and under a selected viewing direction is under comfortable conditions. Continuous Daylight Autonomy (CDA) is a matrix used to calculate light energy use for offices. Effective Outside View (EOV) has been recently proposed to quantify the connection to the outdoors in terms of the amount of view and quality of view[68].

6.1 Daylight glare

Glare is a common problem in many daylit buildings. Problems with glare occur because one part of the visual field is significantly brighter than the larger part of the field to which the eye is adapted. Glare can be avoided by avoiding point light sources, hiding the source, lighting the walls, preventing occupants from seeing bright sources, directly or reflected, diffusing as much light within the space as possible, and using colors that brighten the appearance of a room[3]. Ali evaluated daylight discomfort glare in a better way producing sensible and consistent glare values as compared to the existing evaluation system. The new method was developed with the hope that architects and lighting designers would adopt it as the method for the assessment of daylight system performance[69]. Glare constant Gw is modified by Kim and Koga where exponents related to source size, source position, and

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background luminance are considered. Discomfort glare is caused by a high or non-uniform luminance distribution within the visual field or by high contrasts of luminance between the glare source (window) and its surroundings[68]. Osterhaus states that there are different models to predict daylight glare but all of them have some limitations. Due to the nonuniform distribution of luminance by different shading devices, it is difficult to identify an appropriate glare control device which leads to psychological symptoms[70]. Glare occurs when a too-bright light source falls within the visual field and can cause visual discomfort or even temporary visual impairment. About daylight, glare is mainly related to the view of direct sunlight, which can be avoided by suitable orientation and shading devices[71]. Direct glare is caused by light coming directly to the eye from a light source. Indirect glare is light reflected from a surface in the direction of the eye. Here, glare caused by a large contrast between the highest and lowest luminance levels in the room and glare from direct sunlight reflecting off a glass surface are investigated. Too much contrast makes a room feel gloomy and annoys, distracts, or reduces visibility, and sunlight reflections may cause exaggerated lighting[30]. Nonuniform daylight distribution, glare, and high solar heat gain are studied by Ahmed H. Sheriff on daylight availability in residential desert buildings. He predicted the annual glare using days that employ the DGP metric and divided the glare into four categories: intolerable glare (DGP>45%), distribution glare (45%>DGP>40%), perceptible glare (40%>DGP>35%) and imperceptible glare (DGP<35%). It was studied that cases having imperceptible glare are more than 50% of the occupied time[21].

6.2 Metric for glare

6.2.1 Daylight glare probability

Wienold and christofferson proposed a new daylight glare probability for evaluating glare. It is a better metric for glare measurement as it shows a better correlation with the user's response[72]. In the simulation of daylight glare probability in offices with dynamic window shades Lason Konstantzos have developed the correlations between DGP and design parameters, investigated the behavior and application of DGP and DGPs for shading fabrics with common openness, and analyzed the ability to capture glare for cases with or without sunlight on occupant and studied ability to reduce potential glare from daylight of shading control algorithms. To avoid glare completely at all times very low openness factor (less than 2%) or fully diffused material should be used, assuming DGP is an accurate predictor of discomfort for sun facing instances[73]. Ahmed H. Sheriff divided the glare into four categories: intolerable glare (DGP>45%), distribution glare (45%>DGP>40%), perceptible glare (40%>DGP>35%), and imperceptible glare (DGP<35%)[21]. Konstantzos performed an experimental and simulation study to evaluate daylight glare probability (DGP) in office spaces with roller shades. Using a hybrid ray-tracing and radiosity daylighting model integrated with a glare calculation module[74].

6.3 Glare calculation

6.3.1 Occupant's appraisal

Boubekrit conducted a questionnaire survey by glare appraisals measured on different level scales from satisfactory to intolerable[75].

6.3.2 Glare prediction algorithm

Cornell's large-source glare formula is used to evaluate glare by Boubekrit[75].

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6.4 Glare control

The glare can be controlled by Dynamic Glazing. Lampert states that dynamic glazing is distributed into different parts one is discrete mass movement includes ion and localized electron motion as seen in photorefractive, photochromic, electrochromic, and thermochromic materials and Collective physical movement includes dispersed and homogeneous liquid crystals, and suspended particles, deformable membranes, and adjustable diffraction gratings. PDLC (Polymer dispersed liquid crystal) devices have a good future but are limited by three characteristics: the unpowered state is diffuse, haze remains in the transparent state, and UV stability needs improvement[76]. Takashi and Masayuki prepared an autonomous responsive dimming glass with a combination of two glasses thermotropic glass and low emissivity glass. The autonomous responsive dimming glass showed the properties of shading direct solar radiation and effective utilization of daylight [77]. Piccolo presented the relationship of solar incident angle with solar heat gain[78].

7. Discussion

Literature has shown significant parameters affecting daylight. These parameters will be further taken into consideration for finding out the relation with daylight performance.

8. Conclusion

The relation of all the factors identified with daylight availability can help in improving the visual condition of offices. The interior and fenestration factors are easy to monitor during the designing stage but the external factors are naturally occurring and difficult to optimize. The prediction method using the role of these factors in daylight availability will be a better tool for developing better.

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