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Indoor Light Environment Factors That Affect the Psychological Satisfaction of Occupants in Office Facilities

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Abstract: Recently, human well-being has emerged as a pivotal concern that affects not only quality of life but also social and economic dimensions. Lighting in office spaces is crucial for the health and cognitive function of occupants, and various methods are used to assess it. However, there is still a lack of research investigating the relationship between lighting satisfaction and its key factors in diverse spaces. This study focused on the office light environment, using quantitative and qualitative data analysis to understand occupants' satisfaction and the factors influenced by lighting characteristics. According to the results, occupant satisfaction was higher in light environments with illuminance levels exceeding the appropriate illuminance standard. Furthermore, the influx of daylight and its influencing factors, such as daylight exposure and window size, played a significant role in enhancing satisfaction. However, while daylight was a primary source of glare, its mitigation was not solely reliant on installations, such as blinds; architectural designs, including space arrangement, were also crucial in addressing it. Furthermore, the perception of the lighting environment varied based on work behaviors and spatial arrangements, influencing satisfaction with the lighting conditions. Therefore, a comprehensive approach that considers lighting elements, human behavior, and architectural design is essential in creating a lighting environment for office occupants.

Keywords: human well-being; indoor light environment; daylight; measurement; psychological satisfaction; office facilities

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1. Introduction

Human health and wellness are key topics in fields that look at modern social and economic aspects, along with the improvement of the quality of individual life [1,2]. These trends of focusing on human health, wellness, and individual quality of life have also been emphasized as important in the areas of architecture and interior design [3,4]. On average, people spend 90% of their working hours in indoor spaces. In particular, office facilities account for a large portion of these spaces and are where major social production activities occur [2,5]. Therefore, it is important to create a comfortable indoor work environment that considers its occupants. The indoor environment of a workplace differs from the external environment in various aspects, such as light, sound, heat, and air [6,7]. In particular, changes in physical interactions required as a result of the COVID-19 pandemic have recently changed people's lifestyles in a number of ways, including highlighting the importance of the indoor work environment [8,9]. Among the various factors contributing to the creation of a comfortable indoor workplace, the light environment plays a significant role [10–12]. Creating a pleasant light environment through the integration of daylight and maintaining optimal illuminance levels not only enhances occupants' health, sleep patterns, and cognitive functioning but also significantly boosts their work efficiency [13–17].

Numerous studies utilizing measurements and analytical simulations of illuminance, glare, and spectrum have proposed methodologies to enhance indoor light environments [18–24]. Specifically, by employing these methodologies for office light environments, researchers are investigating the relationship between the light environment and occupants' health, well-being, and cognitive function, thus advancing research on work productivity. However, there is a gap in the literature regarding the examination of occupants' actual satisfaction with lighting conditions in variously shaped office spaces, hindering the identification of crucial factors for improving the light environment.

Therefore, this study sought to quantitatively assess the various lighting conditions in an existing workplace, with a primary focus on office facilities using actual measurements. Additionally, it aimed to analyze occupant satisfaction with the light environments and to identify key factors influencing this satisfaction through surveys. By incorporating occupant perspectives to extract factors related to their perceptions of the light environment and their psychological responses, this research broadens the view of space and light environments in the literature. The results will also serve as a valuable reference for establishing comfortable indoor lighting conditions when designing a space for office facilities.

2. Methods

In this research, the methodology was structured to ascertain occupants' psychological satisfaction with the indoor lighting conditions of their office facilities and to identify factors that influence this satisfaction, as follows:

1. The imperative and distinctiveness of the present study were evaluated by reviewing the prior literature that explored the influence of lighting environments on occupants' work performance, physiological and psychological well-being, and level of satisfaction with the lighting conditions.
2. Target spaces within an office facility were identified based on their unique lighting conditions and spatial configurations. Utilizing an illuminance meter, we quantitatively assessed the primary attributes of the light environment, with a particular emphasis on daylight influx and the resultant illuminance levels.
3. A survey was administered to the occupants operating within the delineated spaces. The aim was to assess their psychological contentment with the prevailing indoor lighting conditions and to identify determinants of this satisfaction, including brightness, exposure, glare, and adjustment of the light environment.
4. We conducted an analysis to discern the prevailing patterns and unique attributes of each designated area in relation to satisfaction with the indoor lighting environment, leveraging the feedback obtained from the occupants' perspectives in the survey.
5. Lastly, by integrating the measured characteristics of the light environment for each designated space with the satisfaction metrics and detailed elements identified through survey analysis, we systematically investigated the correlations among daylight-induced spatial lighting, occupant satisfaction, and the influential determinants of this satisfaction.

3. Previous Reviews

In this section, we examine the relevant issues and topics related to the relationship between the indoor light environment and its users through an analysis of prior studies. Initially, the presentation of our analysis focuses on the impact of the light environment, specifically its influence on human health and cognitive abilities, as we sought to understand the physical effects of light on individuals. Second, we present and analyze past research that surveyed users regarding their experiences with indoor lighting environments. This allowed us to explore how users' psychological responses were influenced by lighting conditions. Finally, drawing from this literature review, we discuss the necessity and distinctiveness of our own research.

3.1. Quantitative Methodology on the Relationship between Light Environment and Human Response

Numerous studies have explored the physical effects of indoor light environments on individuals. These studies have identified various indicators related to health and cognitive function, which significantly impact work performance. To quantitatively measure the physical effects of the light environment, simulation and neurophysics have been used. Boubekri et al. [17] and Lee and Boubekri [20] conducted studies on the effects of the light environment on human health and sleep. Their findings corroborated that spaces with substantial daylight exposure produced favorable outcomes concerning participants' sleep duration, quality, and overall health. Moreover, other research focusing on the light spectrum has delved into the effects of the indoor light environment in office facilities on human health, sleep patterns, and cognitive functioning (Rea et al.) [21] and exposure duration (Anderson et al.) [22]. According to the results of these studies, the more exposure to the blue spectrum of light during working hours (09:00~17:00), the better the quality of later sleep and cognitive functioning [21,22]. Castilla et al. [23] conducted a study on the effect of appropriate indoor illuminance on students' academic achievement. They conducted a memory test and varied illuminance levels while simultaneously monitoring the participants' responses using electroencephalography and heart rate measurements throughout the experiment. Their results showed that memory declined as the illuminance increased, and the highest result was obtained at 100 lx. Zomorodian and Tahsildoost [24] studied the reactions and perceptions of students exposed to illuminance and glare in educational facilities. Research was carried out in four classrooms across two schools in Texas, USA, using both simulation and survey methods to explore correlations between lighting conditions, as defined by LEED (Leadership in Energy and Environment Design) standards, and the students' visual comfort. The findings revealed a strong association between the lighting environment of a space and the students' perceptions of it. Additionally, it was noted that cognitive functions could be influenced by regional, climatic, and cultural variations, which underscores the need for lighting assessment criteria that holistically account for these elements. These research findings underscore the substantial influence of indoor lighting on human well-being. Consequently, the need for an optimal lighting environment becomes even more paramount within office facilities where human health, collaboration, and productivity converge.

3.2. Qualitative Methodology on the Relationship between Light Environment and Human Response

In the current research, an evaluation using a survey was conducted to determine the occupants' responses to the indoor light environment in space. Figueiro et al. [25] used a survey for a comprehensive study covering light, health, and the environment; during the COVID-19 pandemic, the relationship between sleep and health quality according to workers' exposure to light when working from home was investigated. The results showed that exposure to daylight for 1~2 h outdoors or working indoors in a bright room could improve the quality of sleep. Barid and Thompson [26] and Konis [27] conducted post occupancy evaluations (POEs) to gauge worker satisfaction in sustainable commercial and institutional buildings, examining areas such as lighting quality, the balance of daylight and artificial light, and glare (and associated glare issues). While participants expressed overall satisfaction with the lighting conditions, they noted discomfort from the glare produced by daylight, identifying it as a detrimental factor to productivity. Consequently, the research highlighted the critical need to mitigate glare, emphasizing its centrality to worker health and productivity during the design and operation of buildings. In a related vein, Xue et al. [28] delved into the correlation between daylight and occupant comfort within residential buildings. Their findings indicated that both the quantity and uniformity of daylight significantly influenced resident comfort. Furthermore, detrimental effects arising from the excessive use of artificial lighting were highlighted in studies by Alzubaidi et al. [29] and Ferrante and Villani [30]. These researchers investigated the influence of daylight on both workplace efficiency and patient recovery within hospital settings. In a survey of hospital staff, a significant number of respondents expressed the belief that daylight positively enhances work performance and patient recovery by creating a comfortable environment. Consequently, there was a strong preference for daylight inflow.

Survey feedback from hospital staff indicated a predominant sentiment that daylight fosters an enhanced work environment and aids patient recovery. Matterson et al. [31] selected an office space in Barcelona, Spain (a Mediterranean climate), to conduct research on energy use and visual comfort in light environments. The relationship between lighting conditions and energy performance was assessed using both direct measurements and daylight simulations. A survey was administered to gauge participants' preferences for the lighting environment and their use of blinds to achieve the desired conditions. Most of the participants were satisfied with the light environment, with nearly half actively adjusting blinds to create an ideal lighting environment. These data synthesized discussions centered on the creation of spatial environments that harmoniously accommodated energy efficiency and visual comfort through daylight.

3.3. Purpose and Significance of the Study

This study aimed to investigate occupant satisfaction with indoor environments in office facilities where social production occurs. Specifically, we sought to identify and quantify the major factors that influence this satisfaction through measurements and questionnaires. Previous research has established that an indoor light environment, particularly daylight, has a positive impact on occupant health and work efficiency. However, previous studies have limitations in addressing occupants' psychological satisfaction with the light environment of spaces. They often fail to integrate quantitative (measurement) and qualitative (survey) methodologies and neglect to investigate and classify the characteristics of the light environment in various spaces within the building. Therefore, there was a limitation in identifying the key factors affecting occupant satisfaction according to the light environment of these various spaces.

To address this gap, our research took a comprehensive approach. We conducted measurements to quantify the extent of daylight penetration in various spaces and categorized them accordingly. Subsequently, we gathered data on occupant satisfaction with the light environment through surveys and a pattern analysis, differentiating between the spaces. By doing so, we aimed to discern variations in satisfaction levels and pinpoint the specific factors driving these differences.

Ultimately, we derived occupants' psychological changes in response to daylight flowing indoors and factors to be considered accordingly. These factors can serve as valuable reference standards for enhancing occupant well-being and optimizing work efficiency through space and environmental design.

4. Measurement of the Indoor Light Environment for Office Facilities

4.1. Standards for Illuminance of the Workplace

Illuminance is a measure of brightness that quantifies the amount of light emitted from a source per unit area (m^2) for floors and walls; its unit is the lux (lx). Appropriate illuminance criteria are presented according to the type of target space and human activity. In the case of workplaces in offices, the type of activity, according to the standards of the Korean Agency for Technology and Standards, is defined as "visual work for small objects compared to general luminance." The appropriate illuminance according to these activity standards is defined as a minimum of 300 lx, a maximum of 600 lx, and a standard of 400 lx [32]. In addition, the International Commission on Illumination (CIE) proposes 500 lx for general work and 750 lx for precise work [33], and the Illuminating Engineering Society of North America (IES) suggests 300~500 lx [34].

4.2. Selection and Method of Workplace for Indoor Light Environment Measurement

4.2.1. Selection for Target Space

For the measurement, the MH Building of Hongik University (Seoul, Republic of Korea, 37°33′02.6″ N 126°55′33.5″ E) was selected. At the time of the study, the MH Building was the tallest building at the university, with one basement floor and 16 floors above ground, and was a workspace where administrative affairs and professors' individual offices were located (Figure 1). In addition, this building was located on a high location on campus, so the inflow of daylight was not hindered by surrounding buildings, and the accessibility to the researchers was advantageous.

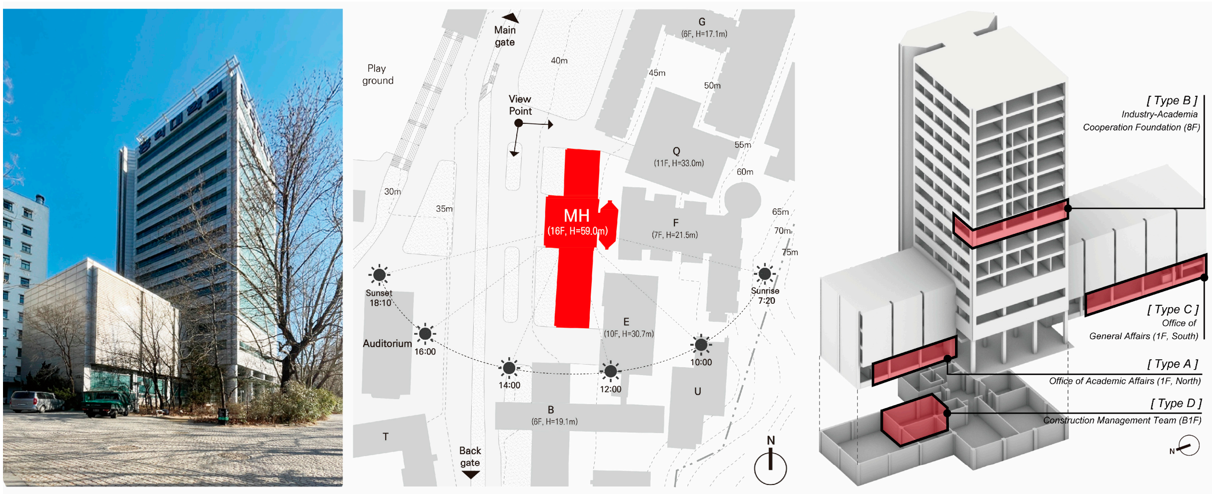

Figure 1. Site plan and photo of the target building (Seoul, Republic of Korea, 37°33′02.6″ N 126°55′33.5″ E).

In the building, located at the same latitude and longitude, we investigated spaces where the occupants perform their work consistently every day, and where various light environments are formed based on the arrangement of windows and desks. In addition to these criteria, there are four spaces inside the MH Building that were finally selected by accepting the experimental request: the Office of Academic Affairs (Type A), the Industry–Academia Cooperation Foundation (Type B), the Office of General Affairs (Type C), and the Construction Management team (Type D).

The spatial characteristics of each space are as follows:

The Type A space was located on the first floor's north side and had a window facing west of the space. Occupants in this space were positioned either facing the window or sideways to it. On the eighth floor, the Type B space had windows on three sides: north, south, and west. Occupants here primarily worked with the windows situated behind them. Like the Type A space, the Type C space was found on the building's first floor on the south side and also had west-facing windows. Workers in the Type C space, except for the team leader's seat at the rear, were stationed beside the window for their tasks. In contrast, the Type D space, located in the first basement, operated entirely under artificial light devoid of any daylight inflow (Figure 2).

In this study, we sought to identify the characteristics influenced by daylight inflow through measurements in four designated spaces. Our selection criteria encompassed the location of each space, the presence of windows, and the configuration of openings and workstations.

4.2.2. Indoor Light Environment Measurement Method

To assess the lighting conditions within each specific space, we employed the four-point method outlined in the illuminance measurement guidelines of the Korean Agency for Technology and Standards (KS C 7612) [35]. The four-point method involves dividing the measurement area into uniform sections, subsequently calculating the average illuminance by measuring the illuminance values at the four corners of each unit area formed by the dividing lines (Figure 3). The illuminance measurements were conducted using a Konica Minolta CL-500A illuminance meter (Konica Minolta, Tokyo, Japan), enabling the determination of both the daylight illuminance and artificial light contributions (Figure 4) [36–38]. While it was challenging to eliminate the influence of artificial light during the measurements, we accounted for this by subtracting the illuminance values obtained from artificial light

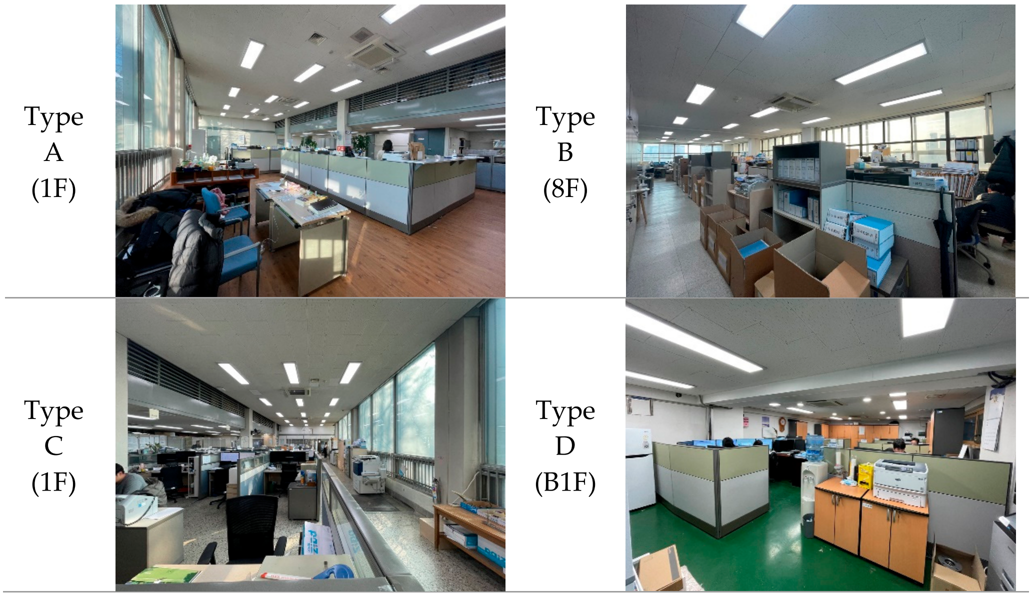

Figure 2. Photos of target spaces for measurement.

measurements taken after sunset from the combined illuminance values under daylight and artificial light conditions.

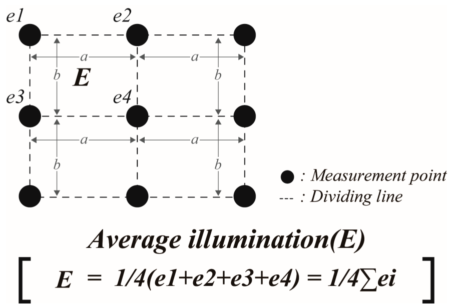

Figure 3. Measurement method (four points).

Figure 4. Illuminance meter (Konika Minolta CL-500A).

To track the changes in daylight influx over time, measurements were taken at three time points with 2 h intervals, starting at 12:00 (12:00, 14:00, and 16:00), except in the morning when no sunlight entered the space, taking into account the movement of the sun and the window positions of the target spaces (Figure 1). Additionally, artificial light measurements were conducted at 19:00 after sunset. To maintain relevance to the work environment, measurements were taken at a height corresponding to the desk level (75 cm above the floor).

The illuminance values for the target spaces were measured on 21–23 February 2023. The space measured on 21 February was the Type A space (1F). The Type B space (8F) was measured on 22 February, and both the Type C (1F) and the Type D (B1F) space were measured on 23 February. During the measurement days, the meteorological conditions in Seoul were characterized by clear skies with cloudiness ranging from 0 to 2. The external illuminance values corresponding to the different measurement time periods are detailed in Table 1 [39].

Table 1. Measurement of external illuminance.

Time	Day		
	21 February 2023	22 February 2023	23 February 2023
12 p.m.	60,083	55,063	51,523
14 p.m.	70,310	68,006	60,840
16 p.m.	33,147	24,886	27,247
19 p.m.	1.2	1.3	1.3

Unit: lx.

The measurements of the illuminance of the target spaces were divided into a unit area of 2 m × 2 m. The measurement points within each unit area were determined as follows: 40 points within the Type A space, 27 points within the Type B space, 40 points within the Type C space, and 12 points within the Type D space (Figure 5).

4.3. Measurement of the Indoor Light Environment of Target Spaces

4.3.1. Type A (1F)

The average illuminance of the sum of daylight + artificial light in the space shown through the measurement was 712.5 lx (12:00), 798.1 lx (14:00), and 1206.2 lx (16:00). These results indicated that the inflow of daylight through the window gradually increased over time (average illuminance of daylight: 93.1 lx at 12:00/178.7 lx at 14:00/586.8 lx at 16:00). In the case of 14:00~16:00, when the inflow of daylight was active, the maximum illuminance values were measured at points P1 and P9, adjacent to the window. Conversely, the minimum illuminance value was measured at the center (P22, P28) and rear corners (P39, P40) of the space.

4.3.2. Type B (8F)

The Type B space on the upper floor of the MH building had windows to the north, south, and west. The average illuminance of daylight + artificial light in the target space through measurement showed high results at 12:00~14:00 compared to the Type A space (917.8 lx at 12:00/1015.9 lx at 14:00/1127.3 lx at 16:00). In addition, the inflow of daylight increased with changes in the sun's position, and the highest illuminance value changed from south to west (P18, P27→P1). In the case of a corridor, which was a space far from the window, a low daylight illumination value was recorded (P21, P23, P24).

4.3.3. Type C (1F)

Table 2 shows the illuminance measurement results of an office located opposite of the Type A space, based on the central lobby of the MH building. In the case of measuring the illuminance of daylight and artificial light, the average illuminance at 12:00 and 14:00 was in the middle of the values measured at the same time for the Type A and Type B spaces (842.3 lx at 12:00/935.7 lx at 14:00); at 16:00, it was similar to the value of the Type A space (1192.4 lx). After 14:00, when the inflow of the daylight increased, there was a rapid increase in illuminance values, except for P7, due to bookshelves on the corridor side (P1 to

P8) adjacent to the window, and low illuminance values were distributed at the rear part located far from the window.

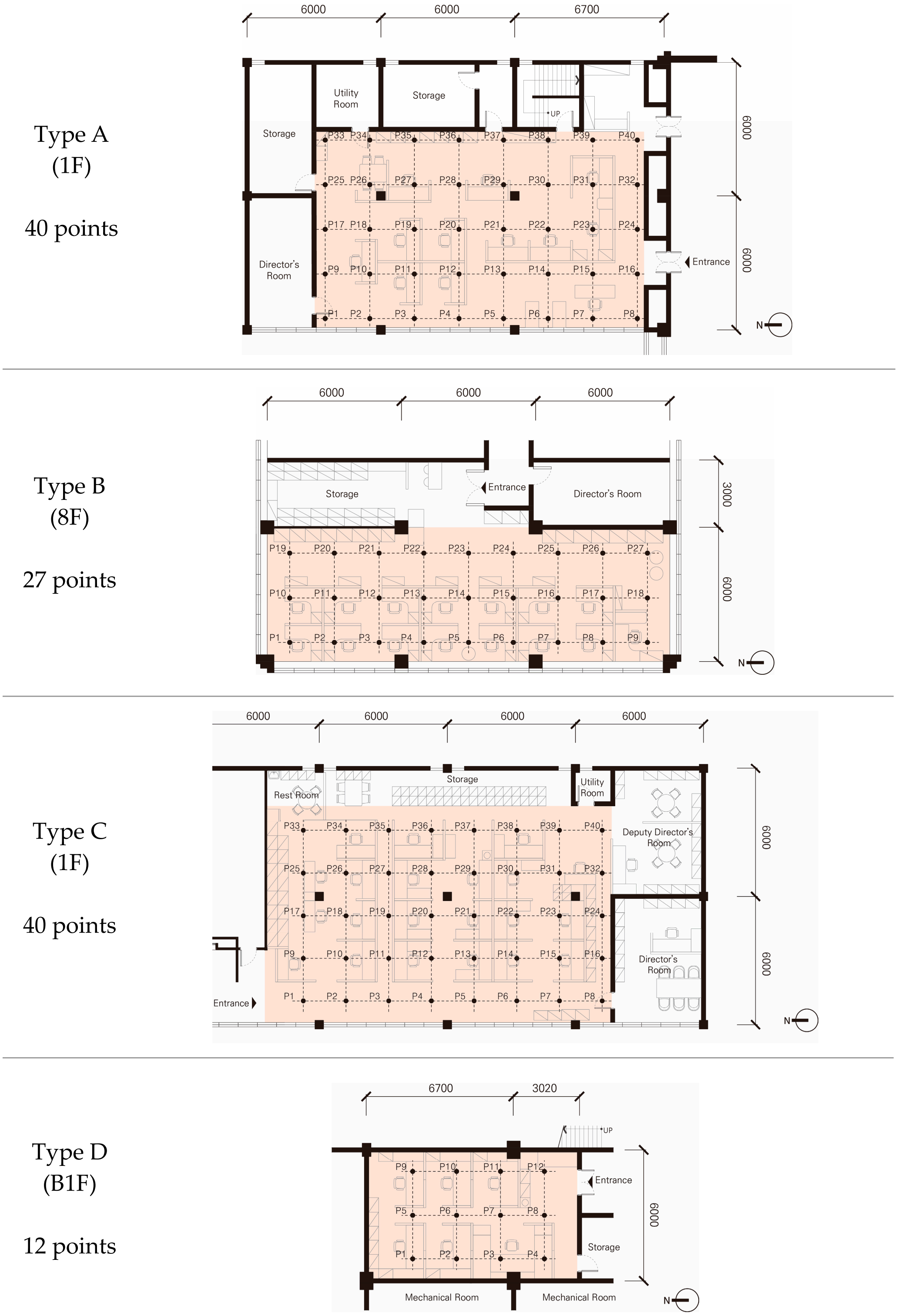

Figure 5. Floor plan and measurement points of the target spaces.

Table 2. Illuminance measurement in target spaces.

Target Space	Time		Daylight + Artificial Light	Daylight *
Type A (1F)	12 p.m.	Maximum	984.2 (P35)	289.4 (P6)
		Minimum	440.4 (P28)	1.5 (P22)
		Average	712.5	93.1
	14 p.m.	Maximum	1498.0 (P1)	1064.9 (P1)
		Minimum	512.7 (P28)	5.8 (P22)
		Average	798.1	178.7
	16 p.m.	Maximum	3791.0 (P9)	3233.6 (P9)
		Minimum	560.9 (P40)	48.8 (P39)
		Average	1206.2	586.8
Type B (8F)	12 p.m.	Maximum	2525.0 (P18)	1550.3 (P18)
		Minimum	494.7 (P15)	31.1 (P21)
		Average	917.8	240.5
	14 p.m.	Maximum	2736.0 (P18)	1769.6 (P27)
		Minimum	625.5 (P11)	68.3 (P23)
		Average	1015.9	338.5
	16 p.m.	Maximum	2318.0 (P1)	1848.3 (P1)
		Minimum	661.3 (P11)	83.7 (P24)
		Average	1127.3	449.9
Type C (1F)	12 p.m.	Maximum	1316.0 (P2)	602.4 (P2)
		Minimum	437.7 (P17)	3.8 (P29)
		Average	842.3	194.1
	14 p.m.	Maximum	1726.0 (P2)	1012.4 (P2)
		Minimum	467.0 (P38)	17.6 (P31)
		Average	935.7	287.6
	16 p.m.	Maximum	3884.0 (P5)	3173.9 (P5)
		Minimum	472.7 (P38)	15.7 (P34)
		Average	1192.4	544.3
Type D (B1F)	12 p.m.	Maximum	940.3 (P11)	-
		Minimum	386.6 (P6)	-
		Average	642.6	-
	14 p.m.	Maximum	969.7 (P11)	-
		Minimum	388.5 (P6)	-
		Average	652.2	-
	16 p.m.	Maximum	957.2 (P11)	-
		Minimum	384.8 (P6)	-
		Average	646.3	-

Unit: lx. * Daylight = (Daylight + Artificial) − Artificial (19 p.m.).

4.3.4. Type D (B1F)

In the case of the average illuminance of the underground workplace, it was found that there was no change in illuminance over time, with values of 642.6 lx (12:00), 652.2 lx (14:00), and 646.3 lx (16:00). Through these measurements, it was demonstrated that the selected underground space had a light environment formed only with artificial light without the inflow of external daylight, which was found to have characteristics of a light environment different from the three spaces in which natural light inflowed.

4.4. Analysis of the Indoor Light Environment of Target Spaces through Measurement

The results for each spatial light environment characteristic through the illuminance of daylight and artificial light measured three times (12:00, 14:00, and 16:00) for four target spaces and the illuminance value of artificial light measured after sunset (19:00) are described in this section.

In assessing the suitability of an indoor lighting environment based on workplace illuminance standards, it was observed that the target spaces where measurements were conducted generally exhibited high illuminance levels. In the case of the Type D space on the first basement floor, it met the illuminance standard of Korea (maximum 600 lx), but the illuminance measured in the other spaces tended to be higher than the illumination standard for precision work recommended by the CIE (750 lx). Notably, the Type B space, located on the eighth floor, featured an overall high illuminance environment compared to the other spaces.

Furthermore, while the Type D space in the basement, which relied solely on artificial light, maintained a consistent level of illumination, other spaces experienced variations in the light environment due to changes in daylight intake over time. In particular, it was observed that the Type A space exhibited the highest variation in the lighting environment between 14:00 and 16:00 (798.1 lx→1206.2 lx).

The influx of light into the spaces was discerned by tracking changes in daylight illuminance. In the target spaces, the increase in daylight varied around the windows, with distinct patterns observed in each space where the measurements were conducted.

The Type A space, situated on the north side of the first floor, showed a transition in the highest daylight influx point from P6→P1→P9, resulting in an inward flow of daylight in a triangular pattern around the northwest corner from the corridor adjacent to the southwest window.

The Type B space on the eighth floor featured windows on the north, south, and west sides, with daylight forming a U-shaped pattern over time, initially centered around the south window at 12:00.

In the Type C space on the south side of the first floor, P2 had the highest inflow point of daylight at 12:00 and 14:00, but it changed slightly to P5 at 16:00. Additionally, the daylight flowed parallel to the window arrangement from the corridor near the windows to the second row of the workspace.

In conclusion, the comparison with appropriate illuminance standards, as well as the characterization of the target spaces based on daylight influx and occupant arrangement within the spaces, can be summarized as follows:

1. Type A (First floor in the MH building)

   The average illuminance at 12:00 and 14:00 in this space was close to the illuminance standard for precision work (750 lx), but an excessive light environment was formed at 16:00. The inflow of daylight was concentrated around the northwest window, so it was expected that the influence of daylight on the occupants at that location would be high.

2. Type B (Eighth floor in the MH building)

   The Illuminance in this space were the highest among all other spaces and the values (917.8~1127.3 lx) exceeded the appropriate illuminance standard. Depending on the arrangement of the windows, the daylight in the space flowed in a U-shape, and the workplace with the window behind it was expected to have a high impact on work and light environment satisfaction.

3. Type C (First floor in the MH building)

The average illuminance in this space was formed at a level similar to that of the IACF, which appeared to be excessive compared to the illuminance standard. Unlike the other spaces, daylight flowed in parallel to the arrangement of the west window, and it was expected that the occupants would be affected by daylight in proportion to their distance from the window.

4. Type D (First basement floor in the MH building)

   This space was appropriately maintained to the illuminance standard (600 lx) among the target spaces where the measurement was conducted. Due to the characteristics of the underground space, the light environment was maintained only by artificial light without the influence of daylight, and it had a uniform light environment regardless of the time of day.

5. Survey of Occupants' Psychological Satisfaction with Their Indoor Light Environment

5.1. Survey Overview

To investigate occupants' psychological satisfaction with their indoor light environment, a survey was administered to 45 individuals working within the spaces where illuminance measurements were taken: 10 individuals from the Type A space, 11 from the Type B space, 15 from the Type C space, and 9 from the Type D space. These participants voluntarily took part in the survey, which was conducted in accordance with protocols approved by the Hongik University Institutional Review Board (IRB).

The survey involved written questionnaires to which the participants responded. The participant demographics included a gender ratio of 44.4% female (20 individuals) and 55.6% male (25 individuals). A substantial proportion of the participants fell within the age group of 30–40 years (20 individuals, 44.4%). The employment tenure reported among the participants was evenly distributed, although it was notable that the Type D space was predominantly composed of workers with more than six years of experience. On average, the participants reported spending 6 to 8 h per day working with PCs.

5.2. Survey Progress and Analysis Method

Following the collection of basic information (including gender, age, years of employment, daily working hours, and working type), we assessed the occupants' overall satisfaction with the workplace light environment.

After the overall satisfaction evaluation, factors influencing occupants' satisfaction with the indoor light environment were categorized into daylight (A), artificial light (B), glare (C), and light environment adjustment (D). Daylight, artificial light, and glare are commonly highlighted in previous studies and sustainable certification systems are noted as crucial aspects of the light environment [40,41]. Light environment adjustment was introduced to explore whether occupants actively seek to improve their satisfaction with the light environment in their workspace. Following the classification of these factors, a survey was conducted based on the characteristics of each factor.

For daylight (A), respondents were asked about their preferences, brightness, and exposure to daylight. Additionally, their awareness of window placement, satisfaction, and appropriateness regarding window size for daylight ingress were assessed.

Regarding artificial light (B), participants were queried about the adequacy of brightness, uniformity, and color.

For glare (C), we inquired about its occurrence within the overall light environment and assessed the resulting difficulties and interruptions at work, categorizing them into those caused by daylight and artificial light.

Lastly, inquiries about light environment adjustment (D) focused on the types of control devices used, their frequency of use, and the availability of additional desk lighting.

Each response utilized a Likert scale (5 points or 10 points) or another nominal scale. Table 3 shows the survey questions used in this study and the scale applied according to each question.

Table 3. Indoor light environment satisfaction survey contents and scales.

		Contents	Scale
		Are you satisfied with the light environment in your workspace?	5 points
Daylight (A)	1	Where do you prefer to work, in natural light, artificial light or mixed? (daylight + artificial light)	Nominal
	2	Do you think natural light is appropriate for your work?	5 points
	3	How much exposure do you have to natural light in your workspace?	10 points
	4	Is there a window near you for the inflow of natural light?	Y/N
	5	How satisfied are you with the size of your workspace window?	5 points
	6	What do you think about the size of the window in your workplace?	5 points
Artificial Light (B)	1	Do you think artificial light is appropriate for your work?	5 points
	2	Do you think artificial light in your workspace is evenly distributed?	5 points
	3	Do you think the color of the artificial light is suitable for your work?	5 points
Glare (C)	1	Does the indoor light environment cause glare at your work?	Y/N
	2	Does the natural light cause glare at your work?	5 points
	3	Does the artificial light cause glare at your work?	5 points
	4	Does the glare of natural light interfere with your work?	5 points
	5	Does the glare of artificial light interfere with your work?	5 points
	6	Does the glare of light on your desk (lamp, etc.) interfere with your work?	5 points
Light Environment Adjustment (D)	1	What device is installed in your workspace to control the indoor light environment?	Nominal
	2	How often do you use a device selected in D1 to maintain a proper indoor light environment at your work?	5 points
	3	Do you have any additional lights on your desk (lamp, etc.) for a proper light environment?	Y/N

Based on the survey results for light environment satisfaction and detailed factors, we analyzed the correlations between the user responses and factors affecting satisfaction by space.

To analyze user responses in each space, this study used a parallel coordinates plot. This graph is used to derive similarities and differences between variables by mapping data into lines for each variable, allowing them to be compared visually. It has the advantage of permitting the analysis of patterns in the data of the participants and their similarities and differences in each space according to the survey contents [42–44].

For the correlation analysis of satisfaction with lighting environments and influencing factors across different spaces, a multiple regression analysis was conducted. It is a statistical method that selects variables with significant effects on a dependent variable among multiple potential independent variables. Through this statistical analysis, this study identified the factors (independent variables) that influenced satisfaction (dependent variable) in each space [45].

5.3. Analysis of Patterns in the Occupants' Satisfaction Responses for the Indoor Light Environment

5.3.1. Satisfaction with the Indoor Light Environment

In the satisfaction survey on the overall light environment of the space (see Figure 6), the Type A (30%) and Type B (72.7%) space workers responded "usually satisfied," and the Type C workers reported being "satisfied" (46.7%). Despite our measurements that showed that their light environment was higher than the appropriate illuminance level, the participants expressed a positive response to this high-light environment.

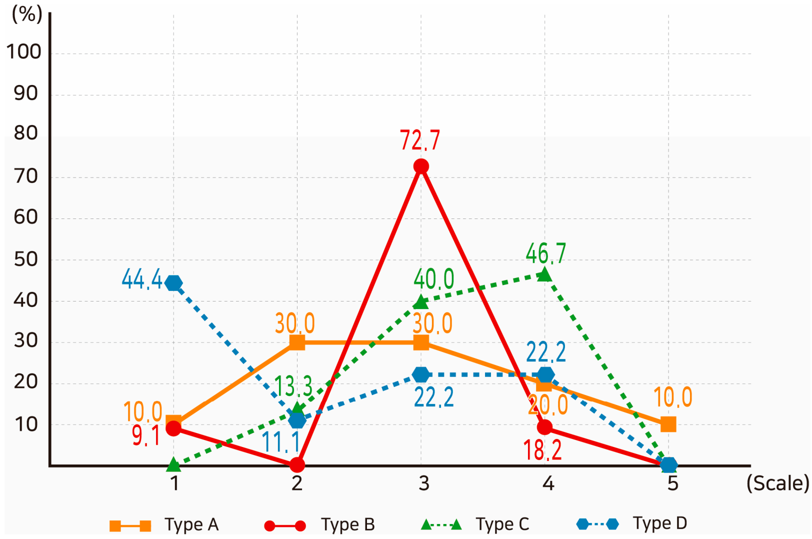

Figure 6. Occupants' indoor light environment satisfaction responses.

Conversely, the Type D space workers, located underground without natural light, showed a very low level of satisfaction with the light environment (44.4%), despite having appropriate illuminance levels according to the established workspace standard. Through the survey responses of the basement workers, it was found that when creating an indoor light environment, it is important not only to comply with the illuminance standard according to the purpose of the space but also to have a natural light inflow.

5.3.2. Daylight

The survey on daylight (see Figure 7) was subdivided into a preference for light environment composition (A1), the adequacy of daylight brightness (A2), daylight exposure (A3), the awareness of windows (A4), satisfaction with window size (A5), and the appropriateness of window size for daylight inflow (A6).

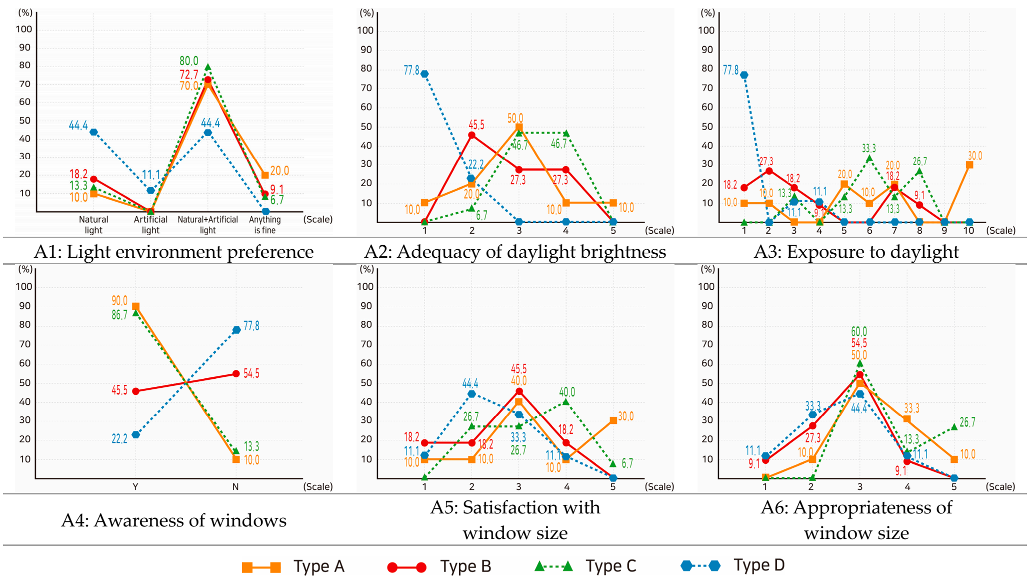

Figure 7. Occupants' responses in the daylight (A) category.

Regarding the users' preferences (A1) for daylight, artificial light, or a mixed light environment, preference for a mixed light environment of natural light + artificial light was high in spaces where natural light was sufficiently inflowed. However, in the basement space, which lacked daylight, workers had a high preference for a light environment consisting only of daylight.

Negative responses were received from the Type B and the Type D users for the adequacy of brightness (A2) and exposure (A3) of daylight. In addition, it was found that the Type A users reported being excessively exposed to daylight (A3).

Regarding the awareness of windows for the inflow of daylight (A4), the Type B users showed lower awareness despite having more windows (on three sides) than the other spaces. Workers in the Type A and Type C spaces responded very positively in terms of satisfaction (A5) and the appropriateness (A6) of window size.

5.3.3. Artificial Light

Questions about artificial light in indoor space were asked by dividing them into specific content (see Figure 8), such as the adequacy of artificial brightness (B1), the uniformity of artificial light (B2), and the appropriateness of the artificial light color (B3). The overall responses were that the brightness (B1) and uniformity (B2) of artificial light in the various spaces were appropriate. In addition, the color of the artificial light currently used (daylight white) was found to be suitable for work (B3). The results of the survey on artificial light were not specific for each space, but the analysis did indicate that the occupants' satisfaction with the artificial light used in all the spaces was positive.

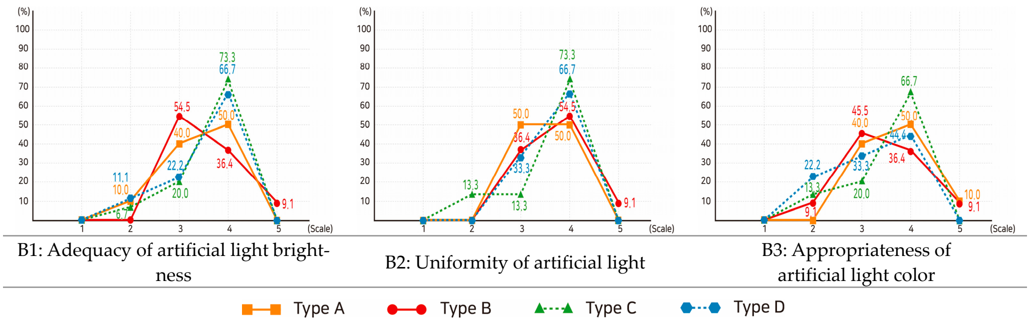

Figure 8. Occupants' responses in the artificial light (B) category.

5.3.4. Glare

The questionnaire items about glare caused by daylight and artificial light are described in this section (see Figure 9). These include items on glare occurrence (C1); difficulties in work due to the glare of daylight (C2) and artificial light (C3); and frequency of work interference due to the glare of daylight (C4), artificial light (C5), and light on desks (C6).

In the case of glare caused by the light environment, the occurrence was reported by the users to be low in the entire target space (C1). As a result of such low glare, difficulties in work (C2 and C3) and frequency of work interruption (C4, C5, and C6) due to glare caused by daylight and artificial light also showed low overall values.

However, the Type A space occupants provided negative responses about the glare of daylight (C2 and C4). This could be seen as highly related to a high exposure to daylight (A3). In addition, it was found that the glare of daylight was reported to be more important than artificial light as a distraction factor during work.

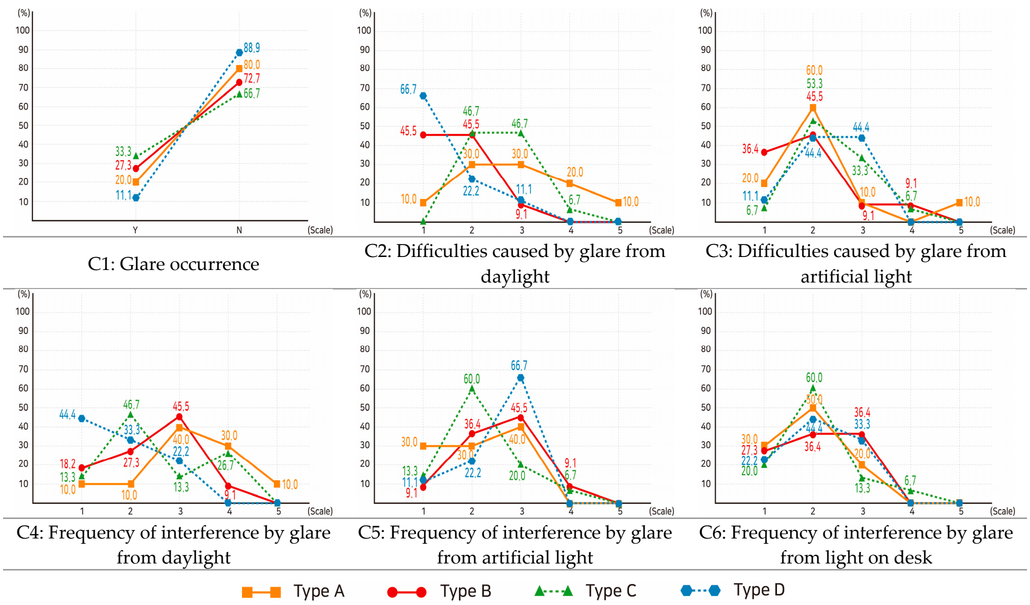

Figure 9. Occupants' responses in the glare (C) category.

5.3.5. Light Environment Adjustment

Regarding adjustments to maintain an appropriate light environment in the target spaces (see Figure 10), the type of light control device (D1), frequency of device usage (D2), and availability of additional lights on the desk (D3) were investigated.

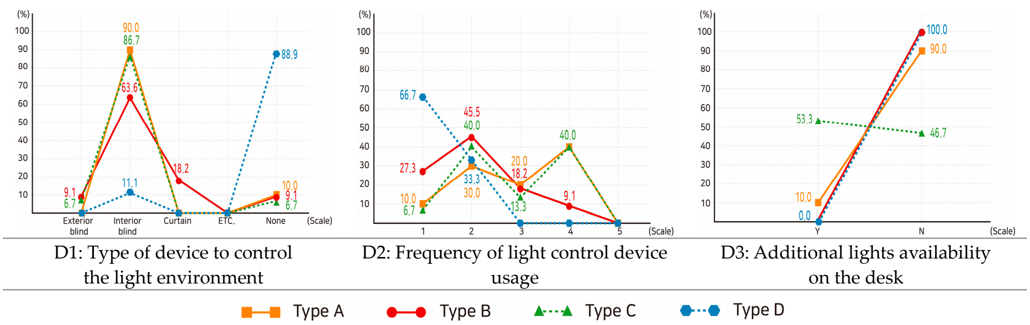

Figure 10. Occupants' responses in the light environment adjustment (D) category.

As a result of the survey, except for the Type D space occupants (who worked in an area where there was no daylight inflow), the users reported adjusting the amount of daylight in the other three spaces using interior blinds (D1). In addition, the Type B occupants reported a low frequency in the use of these blinds, and the Type A and the Type C occupants frequently used them (D2). The occupants' perceptions of daylight according to the degree of exposure (A3) influenced the frequency of use of these blinds. Finally, additional light on a desk (such as a lamp) within the target spaces was not a practice in general; only 53.3% of the survey participants in the Type C space answered that they had one.

5.4. Correlation of Psychological Satisfaction with Light Environment and Major Factors

Based on the collected survey data, IBM SPSS Statistics (version 22), a statistical analysis program, was used to analyze the relationship between occupants' psychological satisfaction with the light environment and the factors influencing it. The dependent variable applied to the multiple regression analysis was satisfaction with the light environment, and all the content items, except for those using the nominal scales, were selected as independent variables (A2, A3, A5, A6/B1~B3/C2~C6/D2).

The selected independent variables met the 95% confidence level criteria ($p < 0.05$) and were analyzed through a stepwise method of the variables by order of high explanator power.

Table 4 shows the satisfaction with the light environment by space according to the multiple regression analysis and the analysis results of the light environment factors that had a major influence on it.

Table 4. Multiple regression analysis of factors influencing satisfaction with the indoor light environment.

Target Space	Independent Variable	Unstandardized Coefficients		Standardized Coefficients	t	p	Collinearity Statistics	
		B	Std. Error	β			Tolerance	VIF
Type A (1F)	A5	0.473	0.192	0.512	2.461	0.043	0.680	1.470
	C4	0.544	0.229	0.495	2.381	0.049	0.680	1.470
	R (0.891)/R^2 (0.794)/F (13.490)/p (0.004)/Durbin–Watson (2.548)							
Type B (8F)	A3	0.183	0.056	0.493	3.281	0.013	0.644	1.552
	A5	0.404	0.139	0.440	2.902	0.023	0.634	1.578
	D2	−0.549	0.122	−0.549	−4.503	0.003	0.979	1.021
	R (0.948)/R^2 (0.898)/F (20.560)/p (0.001)/Durbin–Watson (2.356)							
Type C (1F)	A3	0.352	0.113	0.559	3.099	0.009	0.959	1.043
	A5	0.492	0.194	0.458	2.538	0.026	0.959	1.043
	R (0.791)/R^2 (0.626)/F (10.024)/p (0.003)/Durbin–Watson (2.010)							
Type D (B1F)	C3	1.000	0.354	0.577	2.828	0.012	1.000	1.000
	R (0.577)/R^2 (0.333)/F (8.000)/p (0.012)/Durbin–Watson (1.688)							

Dependent Variable: satisfaction with the indoor light environment. VIF: variance inflation factor.

5.4.1. Type A (First Floor in the MH Building)

As a result of the statistical analysis of the occupants' satisfaction with the light environment of the Type A space, satisfaction with window size (A5, $p = 0.043$) and the frequency of work interference by glare in daylight (C4, $p = 0.049$) were found to be significant (F = 13.490, $p = 0.004$). Significant independent variables for satisfaction were investigated to have an explanatory power of 79.4% according to the coefficient of determination (R^2).

5.4.2. Type B (Eighth Floor in the MH Building)

Through the multiple regression analysis, it was found that the light environment satisfaction of the Type B space workers was affected by exposure to daylight (A3, $p = 0.013$), satisfaction with window size (A5, $p = 0.023$), and frequency of light control device usage (D2, $p = 0.003$) (F = 20.560, $p = 0.001$). In addition, these three variables had an explanatory power (R^2) of 89.8% for satisfaction with the light environment.

5.4.3. Type C (First Floor in the MH Building)

In the case of the Type C workers, exposure to daylight (A3, $p = 0.009$) and satisfaction with window size (A5, $p = 0.026$) were found to have a significant relationship with light environment satisfaction (F = 10.024, $p = 0.003$). The explanatory power (R^2) of the independent variables (A3 and A5) for the dependent variable (satisfaction) was 62.6%.

5.4.4. Type D (First Basement Floor in the MH Building)

As a result of the multiple regression analysis of the construction management team's satisfaction with the light environment for the set independent variables, it was found that there was a significant relationship between difficulties caused by the glare of artificial light (C3, p = 0.012) (F = 8.000, p = 0.012). In addition, the independent variable (C3) with significance was analyzed to have an explanatory power of 33.3% for the dependent variable.

5.5. Psychological Satisfaction and Factors According to the Characteristics of Light Environment by Space

First, the spatial conditions and light environment characteristics were derived through observation and measurement of the four selected spaces. Afterwards, a survey of the occupants was conducted to derive their perceptions and identify correlations for each space regarding their psychological satisfaction with the light environment and the factors influencing it. Based on this, the results of an integrated analysis that linked the spatial and light environment characteristics to the users' psychological satisfaction and the light environment factors that affected it are presented as follows (Table 5):

1. Type A (First floor in the MH building)

   The Type A space had a window on the west side and showed a high level of illuminance at a specific time (16:00). In addition, the workspace was adjacent to the northwest window (P1), which was a location where a high inflow of natural light occurred, and the arrangement was also side facing. In this space, the overall light environment was found to be usually satisfying.
   It was identified that this was because of difficulties at work due to glare (C2) caused by high exposure to daylight (A3) which occurred with a high frequency (C4). In addition, although the size of the window (A5) was satisfying, the use of internal blinds (D2) was found to be high to reduce glare from excessive natural light. Based on this tendency, through statistical analysis, the factors affecting user satisfaction were the size of the window (A5) and the frequency of work interruption due to glare from natural light (C4).

2. Type B (Eighth floor in the MH building)

   Workers in the Type B space, which had three sides open with windows and showed the highest illuminance value, responded that the brightness of the daylight was not appropriate (A2), the exposure was low (A3), and they reported a low rate of window awareness (A4).
   At the time of the study, the Type B space had furniture and objects (documents) placed high on the west-side window with high daylight inflow, and work was carried out with the window behind them. The arrangement of furniture and objects and the type of work were identified as the cause of the occupants' negative responses, and the light environment was reported as being usually satisfying. Similar to this pattern, the regression analysis determined that daylight exposure (A3), window size (A5), and frequency of light control device usage (D2) were major factors affecting satisfaction.

3. Type C (First floor in the MH building)

   The Type C space, which had a window on the west side and showed the second-highest average illuminance value, was found to have no major problems with daylight, artificial light, or glare.
   This resulted in satisfaction with the overall light environment. In particular, the occupants reported high satisfaction (A5), appropriateness (A6) of the size of the window, and users' active adjustment to daylight exposure (A3). It was found that the occupant who worked adjacent to the window used internal blinds (D2) and additional lights on the desk (D3) at the rear, where there was low daylight inflow to create an appropriate light environment. The statistical analysis results found that daylight exposure (A3) and window size (A5) affected satisfaction.

4. Type D (First basement floor in the MH building)

   Finally, the Type D space maintained a light environment without daylight with artificial lighting, and the appropriate illuminance was measured according to the standard (300~600 lx, 750 lx for precision work) regardless of the time of day.

However, it was found that the users were very dissatisfied with the light environment, even though the appropriate levels of illumination were maintained. Negative responses to the appropriateness of brightness for daylight (A2) and exposure (A3) and a high preference for daylight at work (A1) suggest the importance of daylight to occupants in the light environment design. Through multiple regression analysis, a factor that affected the light environment satisfaction of the Type D occupants was difficulties caused by the glare of artificial light (C3), reflecting the status of the light environment in the belowground spaces utilizing only artificial lighting.

Table 5. Characteristics, occupants' satisfaction, and major factors in the indoor light environment.

Target Space	Average Illuminance		Characteristics of Indoor Light Environment	Satisfaction and Major Factors with Light Environment		
				Items	Correlation	Satisfaction
Type A (1F)	12 p.m.	712.5 lx	- 1 window on 1 side of the space (west) - High illuminance indoor light environment at specific time (16 p.m.) - Daylight is concentrated around the window in the northwest (P1) - Arrangement of workspace at the point where daylight inflow is high	A3, A5 C2, C4 D2	A5, C4	Usual
	14 p.m.	798.1 lx				
	16 p.m.	1206.2 lx				
Type B (8F)	12 p.m.	917.8 lx	- 3 windows on 3 sides of the space (north/south/west) - High illuminance indoor light environment - Furniture and items (documents, bookshelves) are arranged high by windows - Occupants work with their backs to the main window (west)	A2, A3, A4	A3, A5, D2	Usual
	14 p.m.	1015.9 lx				
	16 p.m.	1127.3 lx				
Type C (1F)	12 p.m.	842.3 lx	- 1 window on 1 side of the space (west) - High illuminance indoor light environment - Daylight flows parallel to the layout of the window - Occupants are affected by daylight in proportion to the distance from the window to the workplace	A3, A5, A6 D2, D3	A3, A5	Satisfied
	14 p.m.	935.7 lx				
	16 p.m.	1192.4 lx				
Type D (B1F)	12 p.m.	642.6 lx	- Indoor light environment is formed only by artificial light - There is no inflow of daylight - Maintain adequate illuminance regardless of time	A1, A2, A3	C3	Very Dissatisfied
	14 p.m.	652.2 lx				
	16 p.m.	646.3 lx				

A1: preference of light environment; A2: adequacy of daylight brightness; A3: exposure to daylight; A4: awareness of window; A5: satisfaction with window size; A6: appropriateness of window size; C2: difficulties caused by glare in daylight; C3: difficulties caused by glare in artificial light; C4: frequency of interference by glare in daylight; D2: frequency of light control device usage; D3: additional light availability on the desk.

6. Conclusions

It is crucial to establish an appropriate light environment for human well-being, health, and productivity, especially in the workplace where humans spend a significant portion of their time engaging in social production activities. However, many previous studies have not comprehensively utilized quantitative (measurement) and qualitative (survey) methodologies to explore the relationship between light environments and human response. Moreover, research has typically been confined to specific settings within a single space, rather than encompassing various conditions of light environments.

This study aimed to highlight the importance of creating suitable lighting environments for humans, focusing specifically on office facilities. Additionally, we chose to explore various spaces within the same building and conduct physical measurements to analyze factors such as layout, openness, and human behavior. Through this approach, our goal was to assess occupants' psychological satisfaction in relation to the lighting characteristics of spaces and identify the key factors influencing psychological well-being.

To achieve these objectives, we investigated suitable illuminance standards for various workplace activities and analyzed temporal changes and characteristics of the lighting environment within four target spaces situated in the MH building, which housed administrative affairs personnel at Hongik University in Seoul, Republic of Korea. Subsequently, we administered a survey to occupants utilizing these spaces, categorizing the questionnaire into the following sections: satisfaction with the indoor light environment, daylight (A), artificial light (B), glare (C), and light environment adjustment (D). Finally, we synthesized spatial characteristics based on measurements and survey responses to identify the major factors influencing occupant satisfaction with the lighting environment.

Our study findings are summarized in the following paragraphs.

The measured spaces were exposed to an excessive light environment compared to the appropriate illuminance standard. High illuminance values were measured in the Type B and the Type C spaces, and occupants showed overall satisfaction with the indoor light environment. It was understood that the illuminance value that people perceived and were satisfied with was higher than the appropriate illuminance standard currently used. These results suggest reconsideration of the current appropriate illuminance standards.

Daylight played a role in the occupants' satisfaction with the indoor lighting environment. Despite maintaining appropriate illuminance standards through artificial lighting, the Type D area (B1F) occupants reported low satisfaction levels, primarily due to a lack of daylight. Consequently, achieving an optimal indoor lighting environment for human comfort requires the thoughtful integration of both natural and artificial light.

The inflow of daylight is important for an appropriate light environment, but balancing daylight influx with glare reduction measures is also crucial. As shown in the survey results, daylight acted as a major cause of glare (see responses to C2, C4, and D2 from the participants in the Type C space). To reduce the glare of daylight, it is necessary to consider architectural elements (e.g., space arrangement) as well as the use of installations, such as blinds.

Discrepancies were identified between the measurement results and the occupants' perceptions of the indoor light environment, as exemplified by the Type B space. While illuminance measurements indicated higher levels due to abundant windows, the occupants of this space reported dissatisfaction due to obstructed views and workspace configurations. Hence, achieving an ideal lighting environment necessitates a comprehensive understanding of the spatial layout and human behavior.

In conclusion, our study emphasizes the necessity of reconsidering appropriate illuminance standards and underscores the importance of considering various factors that influence occupant satisfaction with lighting, including architectural elements such as spatial layout and furniture, as well as human behavior, in addition to quantitative measurements.

Based on the results of this study, further studies will investigate changes in human physical response using neuro-architectural methodology such as heart rate variability (HRV) and electroencephalogram (EEG), as well as work efficiency through task performance in response to different light environments. Subsequently, by integrating the findings of this study, we aim to propose directions for enhancing workspace light environment standards that comprehensively consider the physical, psychological, and work efficiency aspects of occupants.

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