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THE IMPACT OF WORKPLACE LIGHTING ON EMPLOYEE WELL-BEING AND PRODUCTIVITY: A MEASUREMENT STUDY

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Abstract: The quality of workplace lighting is of significant consequence to the well-being and productivity of employees. This study examines the influence of diverse lighting modalities on employee satisfaction and performance within an intelligent building. In building, three primary lighting modes are used: daylighting, constant illuminance, and power lighting. A survey was conducted with the objective of assessing the perceptions of the lighting conditions held by employees. The findings suggest that the majority of respondents expressed satisfaction with the overall lighting quality, particularly when natural light was integrated with artificial lighting. However, it is notable that there were variations in satisfaction levels, which serves to illustrate the importance of developing lighting solutions that are tailored to specific needs and preferences. The findings indicate that optimal lighting, characterized by appropriate illuminance levels, color temperature, and glare control, can positively impact employee mood, concentration, and overall job satisfaction.
Keywords: natural light, indoor environment, workplace design, human well-being, building performance

1. INTRODUCTION

The quality of workplace lighting has a marked effect on employee productivity. The implementation of an appropriate lighting design and optimization strategy can facilitate an enhancement in overall job performance, which in turn can lead to an improvement in employee well-being. At the present time, two principal categories of lighting are in use: traditional and modern. In buildings that have not undergone lighting renovations or retrofits, traditional lighting remains prevalent and impacts not only employee comfort but also overall energy consumption. Low-pressure mercury lamps were the most common fixtures in such spaces. While these lamps provided

high luminous efficacy, they were frequently misdesigned, leading to over-illumination, glare, and reflections. The inability to adjust color temperature further impacted the quality of illumination. Moreover, these fixtures were energy-inefficient, lacking modern control systems (Douglas et al., 2022, Srivastava et al., 2024, Turan et al., 2020).

In recent years, there has been a notable increase in the retrofitting and replacement of traditional lighting systems with modern LED technology. These systems offer a number of advantages over their predecessors, primarily including low energy consumption and the ability to dynamically adjust photometric properties. Consequently, LED luminaires have made a substantial contribution to the enhancement of workplace well-being. Contemporary lighting systems facilitate the regulation of light intensity based on natural daylight, thereby mitigating glare issues and ensuring optimal illumination levels. Furthermore, these systems permit alterations in color temperature, thereby enabling more effective adaptation to a range of work tasks and supporting employees' circadian rhythms (Kalani and Kalani, 2022, Morales-Bravo and Navarrete-Hernandez, 2022, Turan et al., 2020, Yen et al., 2024).

Every technology has advantage and disadvantage. This is as true of LED lighting as it is of any other technology. The technology employed results in a modification of the color spectrum, with blue wavelengths prevailing in white light. Blue light is widely regarded as having a detrimental impact on workplace well-being. Nevertheless, the utilization of suitable technology and light settings can serve to mitigate this drawback to a degree that renders the light suitable for daily use (Beute and Aries, 2023, Kalani and Kalani, 2022, Kalani and Kalani, 2022, Kruisselbrink et al., 2020, Li et al. 2024).

This article will primarily focus on measuring the light spectrum in a smart building, with a particular emphasis on three main operational modes: daylight, constant lumen output control, and task lighting. The second part of the article will present the findings of surveys designed to ascertain the impact of current lighting configurations on workplace comfort.

2. LIGHTING AND WORKSPACE – LITERATURE REVIEW

The research (Douglas et al., 2022) aimed to investigate the relationship between the built environment and human well-being. To this end, the researchers conducted an experiment with 413 participants, who were exposed to different physical features, including natural materials, windows, and diverse artwork. The effects of these features on stress, creativity, pro-environmental concern, and a sense of belonging were measured using both physiological sensors and self-reported assessments. These findings indicate the potential of the built environment to exert an influence on human well-being. The researchers highlight the necessity of considering the design, experimentation, and operation of human-centered built (for example lighting) environments in order to optimize positive impacts.

Study (Srivastava et al., 2024) examined the influence of workplace spatial characteristics (Inc. lighting) on perceived work performance and well-being in the context of both home-based and office-based work. The study analyzed survey responses from 614 workers in the United States and Canada, with a particular focus on ten workplace attributes. The study indicates that a meticulous approach to

workplace design can enhance both work performance and well-being, harmonizing the advantages of home and office environments.

Research (Morales-Bravo and Navarrete-Hernandez, 2022) was aimed to investigate the relationship between natural lighting in domestic environments and the emotional well-being of residents. The objective of the study was to identify the specific characteristics of natural lighting design that contribute to the experience of positive emotions. The study revealed that the natural lighting conditions in homes exert a significant influence on the perceived levels of happiness and sadness experienced by individuals. Higher levels of natural light entering the home were found to be associated with greater positive emotional states. The findings indicate that the incorporation of natural light into domestic architectural design can have a beneficial effect on emotional well-being. The findings of this research offer valuable insights for architects, interior designers, and policymakers, providing a basis for the creation of more emotionally supportive living environments.

The research (Marzban et al., 2023) was aimed to identify the factors influencing occupant satisfaction, productivity, and health in open-plan offices, with a particular focus on the role of WELL certification. The study analyzed 1.403 post-occupancy evaluation surveys from 14 offices in Australia, New Zealand, and Hong Kong.

The study indicates that while WELL certification can positively impact certain aspects of occupant satisfaction and health, it is not a guaranteed solution. Other factors, such as organizational culture, management practices and individual preferences, also play a significant role.

The objective of research (Turan et al., 2020) was to ascertain the economic value of natural light in office spaces. The study employed urban daylight simulation and a hedonic valuation model to ascertain the following findings:

• High Daylight Premium: The premium for offices with high levels of natural light (55% spatial daylight autonomy) is 5-6 % higher than that for offices with low levels.

• Daylight Distribution: The study simulated the distribution of daylight on individual office floors, taking into account architectural and location-specific factors.

• Daylight Value: The value of daylight was found to be independent of other building, neighborhood, and contract characteristics.

The findings suggest that daylight is a significant factor in the valuation of office space and should be given priority in design, policy, and planning decisions. By incorporating natural light into building design, developers and landlords can create more valuable and desirable office spaces.

The objective of study (Jamrozik et al., 2019) was to investigate the impact of two modern shading systems (motorized mesh shades and automatic tinting) on occupant well-being and performance in a controlled office environment. The principal findings were as follows:

The results demonstrated a number of positive impacts.

- Improved cognitive function: Both shading systems resulted in enhanced working memory and inhibition when compared to a baseline condition with no daylight or view.
- Enhanced satisfaction: The participants expressed greater satisfaction with the light and the overall environment in both shading conditions.

- Decreased incidence of eyestrain: Both systems demonstrated efficacy in reducing symptoms of eyestrain.

The findings of study (Jamrozik, 2019) indicate that the provision of access to daylight and an unobstructed view through the use of contemporary shading systems can have a beneficial effect on the well-being and performance of occupants in office environments. Both motorized mesh shades and automatic tinting can effectively mitigate glare and provide a comfortable and productive workspace.

The study (Kalani and Kalani, 2022) proposes a novel approach to controlling the correlated color temperature (CCT) of high Color Rendering Index (CRI) LEDs in order to align them with human circadian rhythms and the time of day. The system is designed to imitate the natural progression of light from sunrise to sunset, with the objective of enhancing well-being and performance in a range of indoor environments. The study establishes a mathematical model for determining the CCT based on the time of day. The model is then employed to regulate the CCT of LEDs by combining the light output of 2700 K and 6500 K LED channels. The simulation outcomes illustrate the efficacy of the proposed methodology.

This system has the potential to be deployed in a range of settings, including commercial premises, educational institutions, healthcare facilities, and smart cities. By addressing the long-term impact of artificial lighting on human performance and efficiency, this method can contribute to the overall well-being of individuals.

3. METHODOLOGY

This study analyses the history of the smart building, with particular emphasis on three distinct lighting types: daylight, artificial lighting with constant intensity, and power artificial lighting. In instances where artificial illumination was employed, a proportion of natural light (with the exception of nocturnal hours) was used as supplement or augment the characteristics of the artificial lighting.

The results of study include the implementation of measurements for the three aforementioned lighting modes. For each mode, the spectral range of wavelengths was determined, along with primary photometric data focusing on the perception of light and color.

A simplified flowchart, presented in Figure 1. provides a clearer visual representation of the methodology employed. The methodology comprises two principal stages: firstly, data collection, which encompasses both measurements and survey responses; and secondly, data processing and analysis. This methodology allows for the analysis of any given space or workplace, thereby ensuring the broad applicability of this research in practice.

The second phase of the study focused on the administration of a survey pertaining to the subject of workplace lighting. Based on survey results the differences in the ability to perceive light and in subjective feelings among employees will be determinate.

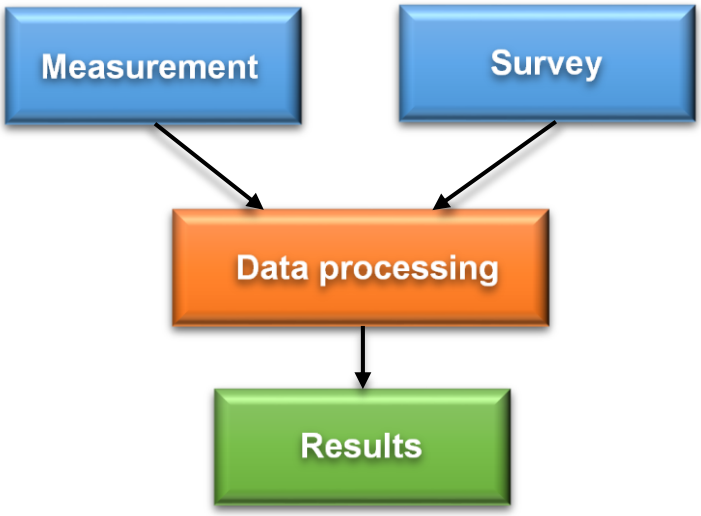

Fig. 1 Block diagram of methodology

4. MEASUREMENT OF LIGHTING

The principal objective of this study was to analyses the lighting in the workspaces of an intelligent building. The intelligent building permitted the implementation of a three lighting scenarios.

4.1 Daylight

It is widely accepted that natural light is the optimal source of illumination for any work task. However, the use of natural light is not without its disadvantages. These include variability throughout the workday due to weather conditions and other factors. The building's orientation allows for the classification of natural light usage into two distinct categories: east-facing and west-facing. The east-facing areas of a building receive a substantial amount of natural light during the morning hours, which can occasionally result in excessive glare due to the sun's position on the horizon. Conversely, west-facing areas experience a deficiency of natural light in the morning and an excess in the afternoon. Glare is primarily a concern outside standard working hours, which makes it a relatively manageable issue. However, during periods of extended work, such as overtime, the presence of excess light in these areas can have a detrimental impact on workplace comfort. This mode of lighting is the most energy-efficient, as it eliminates the necessity for artificial lighting.

The Figure 2 presents a spectral analysis of the conditions of daylight. The values and the uniform distribution of wavelengths correspond to the spectral range of natural daylight, as defined by the International Commission on Illumination (CIE). This mode may be regarded as a reference point against which the characteristics of artificial lighting conditions can be evaluated.

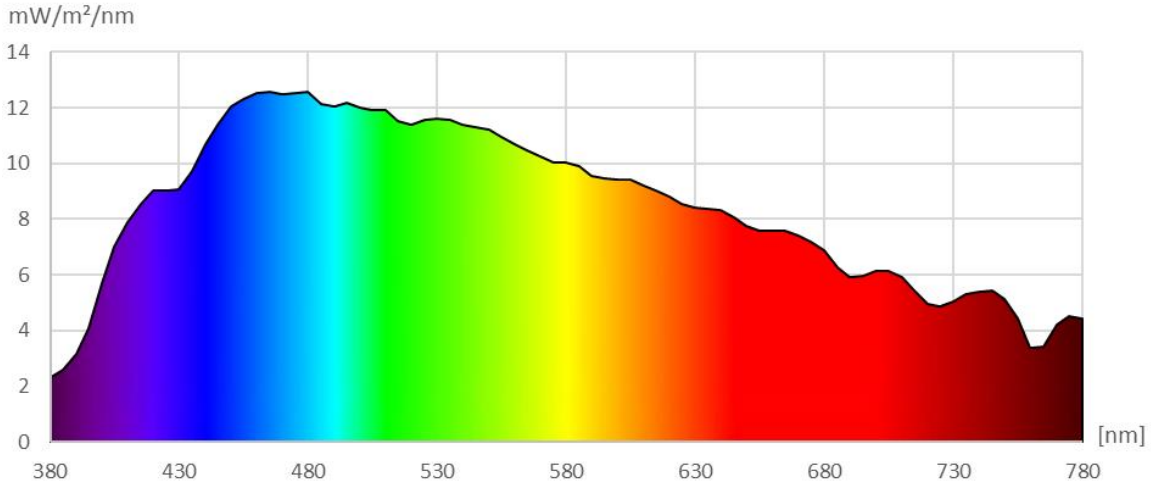

Fig. 2 Spectral analysis of daylight

The following Table 1 presents the fundamental parameters of lighting, which are crucial for the evaluation of visual comfort. It is evident that natural light provides an optimal light source for work, ensuring overall visual comfort based on these data.

Table 1
Photometric values of daylight

Illuminance	764.05 lx
LER	223.3 lm/W
Correlated Color Temperature	6633 K
Saturation	8%
Dominant wavelength	489 nm
Peak wavelength	477 nm
Flicker frequency	% < 1.0
Percent Flicker	< 1.0
Flicker index	% < 1.0
Ra	96.6

4.2 Lighting with constant intensity

Lighting systems with regulation on constant intensity are designed to automatically adjust the overall light intensity in a given space, utilizing light sensors and intelligent control mechanisms. By integrating seamlessly with natural daylight, these systems provide optimal visual comfort for occupants. By continuously monitoring ambient light levels and automatically adjusting the lighting accordingly, energy savings of up to 70% can be achieved in comparison to traditional lighting systems. This mode is particularly well-suited to offices and other workspaces, where high productivity and comfort are essential. While allowing for individual settings in different areas, its greatest advantage lies in its ability to automatically respond to changes in the ambient environment, thereby ensuring optimal lighting conditions throughout the day. A spectral analysis of the light source revealed a blue shift in the peak wavelengths, indicating a higher proportion of shorter wavelength light. This shift can be attributed to use LED lighting technology (Figure 2). Moreover, the analysis demonstrated an increase in the proportion of blue light within the spectrum, which is likely attributable

to the specific color characteristics of the LEDs utilized. These findings have implications for human health and well-being, as exposure to blue light has been demonstrated to affect circadian rhythms and well-being patterns.

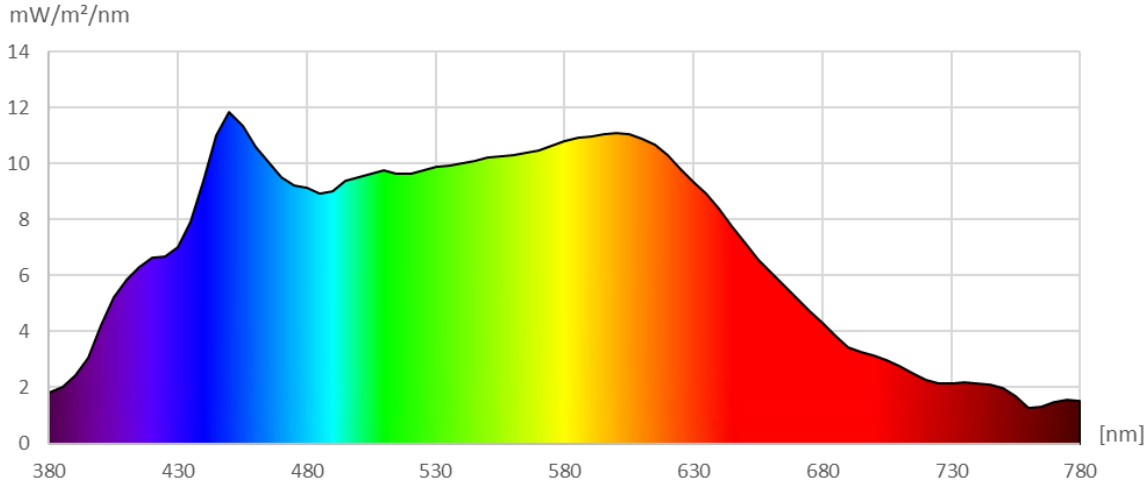

Fig. 3. Spectral analysis of constant intensity lighting

The results of the measurements (Table 2) demonstrate that all lighting parameters in the space have been modified. The most notable alteration is a change in the dominant wavelength, with a shift towards the red end of the spectrum. This shift is directly correlated with a decrease in color temperature to approximately 5236 K, which indicates a warmer light. Furthermore, the color rendering index has decreased, which may have a detrimental effect on visual comfort and task performance.

Table 2
Photometric values of constant intensity lighting

Illuminance	773.9 lx
LER	259.0 lm/W
Correlated Color Temperature (CCT)	5236 K
Saturation	4.6%
Dominant wavelength	570 nm
Peak wavelength	451 nm
Flicker frequency	% < 1.0
Percent Flicker	< 1.0
Flicker index	% < 1.0
Ra	94.9

4.3 Power lighting

In this mode, the influence of natural daylight is not primarily used, and the artificial lighting system operates at maximum output irrespective of the time of day. This configuration is typically employed in spaces where high levels of illumination are required for the completion of specific tasks or by individuals who perceive the previous lighting conditions to be inadequate. Given that the artificial lighting system is continuously operational, this mode is associated with the highest energy consumption.

A visual inspection of the Figure 4 reveals a significant alteration in the light spectrum. A notable shift in energy distribution has occurred, with a substantial portion of the energy being redirected towards the red end of the spectrum. This is accompanied by a significant attenuation around 480 nanometers. The results of the spectral analysis confirm the presence of two distinct peaks in the blue and red regions of the visible spectrum. This spectral profile is indicative of the LED technology employed, which is known to produce such characteristic emission spectra.

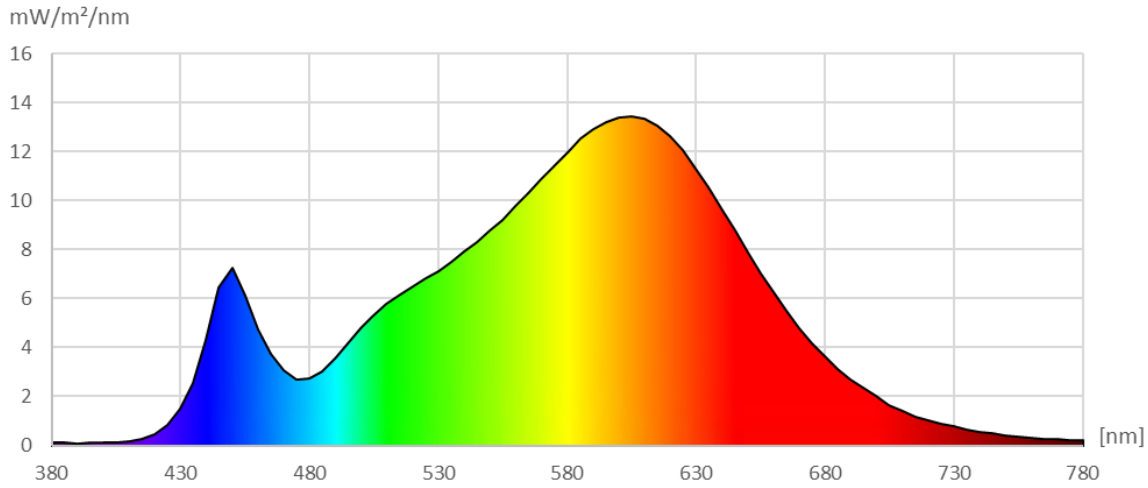

Fig. 4. Spectral analysis of power lighting

A notable divergence from natural daylight conditions is evident in the considerable reduction of CCT by over 50 %, reaching a value of 3085 K (Table 3). This lower CCT positions the light source firmly within the warmer white region of the color temperature scale, deviating considerably from the CCT typical of daylight. Concurrently, a shift towards longer, red wavelengths is observed, which reinforces the decrease in CCT. Furthermore, the color rendering index has decreased to 82.5, which indicates that the light source is unable to accurately reproduce colors. A reduction in color rendering quality may have an adverse effect on visual comfort and task performance, impairing the ability to discern shapes and colors and consequently reducing overall worker productivity.

Table 2
Photometric values of constant intensity lighting

Illuminance	677.55 lx
LER	327.6 lm/W
Correlated Color Temperature (CCT)	3085 K
Saturation	49.60%
Dominant wavelength	581 nm
Peak wavelength	606 nm
Flicker frequency	% < 1.0
Percent Flicker	< 1.0
Flicker index	% < 1.0
Ra	82.5

5. SURVEY OF LIGHTING CONDITION

In order to evaluate the various lighting modes within the workspace, a survey was designed to assess the subjective experiences of individuals. The survey was divided into four sections. The initial section of the survey was designed to gather information pertaining to the respondents' demographic characteristics. The second section of the survey was designed to assess the existing lighting conditions. The third section of the survey inquired about the respondents' perceptions of the impact of the lighting on their work-related tasks. The final section of the survey invited respondents to suggest potential improvements to the workspace lighting.

5.1 Demographical data

The survey yielded a high response rate of 87 % among the targeted employees, thereby providing a substantial dataset for analysis. The demographic analysis revealed a workforce that was predominantly male, with men accounting for 69.6 % of respondents and women for 26.1 %. A small proportion of respondents identified as other genders, but this group was insufficient in number to significantly influence the results. The length of employment exhibited a considerable range, spanning from three months to 58 years. This variability renders it challenging to derive meaningful insights based on this variable. Accordingly, employment duration was excluded from the overall analysis. The majority of respondents (approximately 90 %) reported spending between six and eight hours per day working at a computer. Given the fluctuations in natural light levels throughout the day, the duration spent working at a computer can have a significant impact on an individual's perception of and requirements for lighting.

5.2 The assess of existing lighting conditions

In the majority of cases, 91.3% of respondents indicated that the lighting intensity was suitable and sufficient. However, this assertion is somewhat contradicted by the fact that when asked if the lighting was too bright, only 78.6% of respondents answered negatively, while the remaining 21.4% considered the lighting too strong. In conclusion, the current lighting setup is deemed suitable and sufficient during certain periods of the day. However, when there is an abundance of natural light, the room can become excessively bright.

In response to the question regarding the impact of the lighting on their eyes, the results were more positive. The majority of respondents (69.9 %) indicated that the lighting was perceived as pleasant, while the remainder indicated that it was not or was only slightly so. This high proportion of positive responses can be attributed to the current lighting setup, which primarily combines natural and artificial light, resulting in a suitable composition and color of light. These findings are further supported by the following question about eye strain and discomfort, where 60.9 % of respondents reported no issues. In evaluating the current lighting configuration, 82.6 % of respondents indicated that the existing setup was deemed suitable, whereas the remaining individuals reported an unsatisfactory light composition. This can be attributed to the configuration of the lighting system and the layout of the space, which present significant challenges from a lighting perspective.

5.3 Impact of light to work task

The results of the survey indicated that the majority of respondents (87 %) had sufficient access to daylight, which suggests a correlation between natural light exposure and mood (52.2 %). Approximately half of the respondents indicated that the color of light had an influence on both their mood and work performance. Given the high level of natural light exposure, it can be concluded that lighting has an impact on concentration during working hours. Overall, approximately 69.6 % of respondents confirmed that lighting had an influence on their mood and concentration. These findings lend support to the general use of natural light and the prevailing lighting configuration, indicating that lighting itself exerts a considerable influence on overall work mood and concentration.

5.4 Suggest potential improvements to the workspace lighting

The one of objective of the survey was to ascertain the changes that respondents would like to see implemented. In the majority of cases, respondents expressed satisfaction with the existing lighting conditions. However, in three instances, respondents indicated that the lighting intensity was excessive and proposed that the lighting should be equipped with an automatic intensity adjustment mechanism. In two instances, the respondents proposed the installation of supplementary illumination in the work area. One respondent indicated that the current lighting intensity was insufficient and required augmentation.

The survey can be considered an effective instrument for the collection of requisite data. The results unambiguously indicate that the existing lighting configuration in the workplace is appropriate and has a beneficial effect on employee performance, mood, and concentration. Notwithstanding the aforementioned favorable outcomes, it is recommended to consider the additional data obtained in order to further enhance the lighting and promote overall workplace well-being.

6. DISCUSSION

The results of our study demonstrate a significant correlation between workplace lighting and employee well-being. The majority of participants indicated a preference for lighting environments that incorporated natural daylight. This is consistent with existing research indicating that natural light has a beneficial effect on mood, productivity and overall well-being. However, the survey also revealed several lighting-related challenges, including glare and limited control over light intensity. These findings highlight the necessity of designing lighting systems that address these issues and provide optimal lighting conditions, with the aim of enhancing employee satisfaction and performance.

The three lighting modes under investigation displayed clear differences in their spectral characteristics. The participants consistently demonstrated a preference for natural daylight. However, the variability of natural light, particularly in terms of intensity and spectral composition, can present challenges in maintaining optimal visual conditions for a range of tasks.

In contrast, purely artificial lighting often produces a spectral power distribution that differs significantly from natural daylight, which can result in reduced visual acuity and discomfort.

Lighting systems, which combine natural and artificial light sources, provide a more adaptable and customizable solution. By intelligently controlling the intensity and spectral composition of artificial light in a manner that complements the available daylight, these systems can create lighting environments that closely mimic the qualities of natural light. Although the spectral characteristics of artificial light may still differ from those of natural daylight, dynamic lighting systems can significantly reduce these discrepancies. The assertion is corroborated by photometric data, which indicates that the spectral variations between dynamic lighting and natural daylight are less pronounced than those between pure artificial light and natural daylight.

It is important to note that all three lighting modes complied with the EN 12464-1 standard (EN 12464-1, 2023). Therefore, it is essential to consider that the results may be somewhat subjective.

In light of the findings of the survey, a number of recommendations can be put forward with a view to optimizing lighting and improving energy efficiency.

- **Maximize natural light:** Design lighting systems to optimize natural light for energy savings and improved well-being.
- **Automate lighting control:** Implement automated systems to adjust light intensity based on occupancy, time, and other factors.
- **Include manual control:** Provide manual override options for personalized lighting preferences.
- **Regular maintenance:** Implement regular maintenance to ensure optimal performance and energy efficiency.

7. CONCLUTIONS

The quality of lighting in the workplace has a significant impact on the well-being of employees. By modifying illuminance levels, color temperature and glare, it is possible to enhance overall work performance and improve the work environment. The objective of this study was to evaluate the impact of lighting on employee job satisfaction and efficiency. An anonymous survey was conducted with the objective of objectively assessing the aforementioned parameters. The principal objective of the survey was to analyses the existing lighting conditions within the intelligent building and to utilize the findings as a key indicator of employee satisfaction with the various lighting settings.

The results of the study demonstrate that lighting has a marked effect on employee concentration, performance, and satisfaction. The initial data provides optimal feedback for work environment adjustments, allowing for the implementation of a more refined lighting system, which should enhance overall satisfaction.

The results of the survey indicate that approximately 70 % of respondents expressed satisfaction with the current lighting. However, the remaining 30 % of respondents raised concerns regarding specific aspects of the lighting, which can often be addressed through appropriate lighting adjustments.

Further research should investigate the relationship between lighting and employees in greater depth, with a particular focus on visual comfort and the impact of lighting on the human circadian rhythm.

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