

Article

Research on Dynamic Monitoring and Optimization of Lighting Environment in Clothing Workshop Based on Visual Comfort

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Abstract: T8 LED tubes with adjustable brightness and color temperature are installed in the workshop for workers to adjust their lighting independently. The illuminance of the workers' working surface is dynamically monitored for one year, and the collected illuminance data are quantitatively analyzed to explore the suitable illuminance threshold and color temperature preference for workers in real scenes. The illuminance value is divided according to time period and season, which provides reference for the development of intelligent buildings. For the three workflows in the post-finishing workshop, the lighting environment was optimized based on the uniformity of illumination, and the optimal height of the lighting arrangement was determined. The optimal luminaire placement height for the bar tacking machine was found to be 1.28 m, for the auxiliary workbench it was 1.02 m, and for the ironing table it was 1.2 m.

Keywords: dynamic monitoring; illuminance; linear light source



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1. Introduction

Indoor environmental quality is a crucial factor for assessing the health of living environments in buildings. Previous studies have shown that improving indoor environmental quality can effectively enhance work efficiency and environmental satisfaction [1–3]. Inappropriate indoor environments can have adverse effects on the physical health of occupants, increasing the potential risks of building-related illnesses and Sick Building Syndrome (SBS) [4]. Indoor environmental factors include ventilation, natural lighting, artificial lighting, sound, temperature, and humidity [4]. These factors, with varying weights, influence indoor environmental quality, and lighting is considered as one of the most influential factors in the human living environment [5]. A comfortable natural lighting environment is of significant importance for work efficiency and visual health, and it has a substantial impact on people's well-being [6,7]. Commonly used indicators for evaluating visual comfort in naturally lit office spaces include desktop horizontal illuminance related to horizontal working modes, illuminance uniformity, and glare [8].

Veitch, Stokkermans, and Newsham [9] analyzed data on workers' subjective preferences for the lighting environment, mood, and personal satisfaction with the work environment to establish a lighting model. They found a close relationship between the factory lighting environment and workers' work efficiency, physical and mental conditions, as well as behavior. Henri, Wouters, Tenner [10] used technical means to control the lighting environment at the workstations, allowing workers to independently adjust the work lighting environment. After comparing the data, they found that different lighting environments also led to differences in workers' visual fatigue, alertness, and productivity under otherwise identical conditions. They conducted experiments to determine the optimal illuminance adjustment for assembly workers, with an adjustable illuminance range of 100–3380 lux. The work surface lighting fixtures could be automatically switched, and

after frequent experiments, the average optimal illuminance for assembly workers was found to be 1752 lux. Moore and others conducted similar experiments in an office with a horizontally adjustable work surface. The office had windows, and artificial lighting and natural daylight were independent of each other. The adjustable illuminance range for artificial lighting was 200–2000 lux. The research results indicated that the choice of optimal illuminance depends on the specific time of day, and the optimal illuminance range for artificial lighting adjustment was found to be 700–1100 lux [11,12].

Hartstein [13] and Motamedzadeh [14] found in their studies that higher correlated color temperature (CCT) lighting can improve attention, enhance work capacity, reduce reaction time in executive function tasks, and increase work efficiency and quality. Motamedzadeh [14] investigated the impact of LED lighting on cognitive and executive abilities in visual space and found that cold-colored light (high CCT) enhances the cognitive system's ability to process multiple task representations, they discovered that using white light rich in blue light, compared to lower CCTs, can enhance alertness and cognitive performance in night shift workers, especially in improving sustained attention. Shamsul M [15] conducted experiments and found that lighting with a CCT of 6200 K resulted in higher subjective alertness and typing accuracy compared to lighting with CCTs of 4000 K and 2700 K. Viola [16] compared the effects of different CCTs (17,000 K and 4000 K) of white light on alertness in office workers and found that higher CCT lighting significantly improved subjective alertness and work performance. Küller [17] investigated the variation trends of people's mood influenced by natural light in four countries and found that residents in countries with seasonal variations also experienced seasonal mood changes, indicating the influence of light intensity on mood. However, overly bright or dim lighting is unfavorable for emotional experiences, often leading to negative emotions such as restlessness and unease [18]. McCloughan [19] conducted research and found that in low CCT environments, as illuminance increases, participants' feelings of anxiety and hostility gradually increase, while in high CCT environments, as illuminance increases, participants' feelings of anxiety and hostility gradually decrease. The influence of lighting on emotions also varies for different genders. Male participants' hostility slightly decreases with increasing CCT, and their feelings of unease significantly decrease as illuminance increases. On the other hand, female participants' hostility significantly decreases with increasing CCT, while their feelings of unease gradually increase as illuminance increases. In addition to CCT and illuminance, the lighting's color rendering properties, duration, and participant age also affect emotions.

In an appropriate lighting environment, light can help regulate circadian rhythms [20], improve sleep quality [21], and enhance mood [22]. Higher CCT lighting can improve attention and reaction time in certain cognitive tasks [23]. Hartstein [13] further investigated the effect of light source CCT on arousal levels during cognitive work. They found that higher CCT lighting led to fewer working memory errors, reduced sleepiness, and fewer omission errors and reaction times during sustained attention tasks. Higher CCT lighting is more in line with lighting's impact on the biological rhythm, resulting in better sleep efficiency and quality, and less sleepiness during night shifts. Küller [24] studied participants' electroencephalogram (EEG) patterns in a simulated office environment with varying illuminance levels. The results showed that higher illuminance levels resulted in fewer delta waves (indicating sleepiness), suggesting that bright light helps maintain central nervous system alertness. Van Bommel [25] pointed out that working under high illuminance levels leads to higher alertness and concentration, which is beneficial for improving visual task performance.

Research Questions

The existing studies have proposed reference ranges for appropriate illuminance thresholds for workers, but they have not been subdivided based on job type and season. This paper aims to monitor the real-time illuminance in different work areas of the post-finishing workshop in a garment factory, explore the appropriate illuminance thresholds

for different job types in a dimmable lighting environment, and subdivide them based on season and time periods. It also provides recommendations for the future development of smart buildings. Additionally, the paper optimizes the layout of light sources in existing factories based on the appropriate illuminance thresholds, using uniformity as the optimization parameter, and determines the optimal height for arranging lighting fixtures.

2. Experimental Design

2.1. Experimental Conditions

The experimental site is located on the fourth floor of a clothing factory in Handan, China, specifically in the post-finishing workshop. The geographical coordinates of the site are, approximately, longitude: N 114.495 and latitude: E 36.604. The lighting method employed in the workshop is a combination of side window lighting and localized illumination. The workshop features windows facing both north and south, constructed with transparent colorless glass and without any shading system.

For the experiment, 24 female workers from the post-finishing workshop were selected as research subjects. The participants had an average age of 44 ± 4 and possessed more than 15 years of work experience. To ensure the reliability of the experiment data and the proper conduct of the study, the participants were chosen to have normal or corrected vision and were free from any other eye diseases or medical conditions that could potentially interfere with the study.

2.2. Illuminance Acquisition System

The illuminance acquisition system in this study comprises three main components: a host computer, a 485 bus, and illuminance sensors, as illustrated in Figure 1. To ensure smooth communication and accurate data acquisition between the devices, the system utilizes the Modbus-RTU communication protocol. The 485 system employs differential signal transmission for data transfer. During data transmission, the transmitter converts the data into differential signals, with the A-line transmitting positive voltage levels and the B-line transmitting negative voltage levels. This approach generates a voltage difference based on the transmitted data, facilitating reliable data transmission by effectively canceling out noise and interference. Consequently, the system exhibits enhanced signal reliability and anti-interference capability. The illuminance sensor used in this experiment has a range of 0 to 200,000 lux, with an accuracy of $\pm 5\%$. The system operates in a point-to-multipoint communication format, where the host computer sends illuminance acquisition commands to the illuminance sensors. The sensors receive and parse these commands to execute the corresponding operations. Subsequently, the sensors transmit the execution results or response data back to the host computer. The host computer receives and responds to the received data [26].

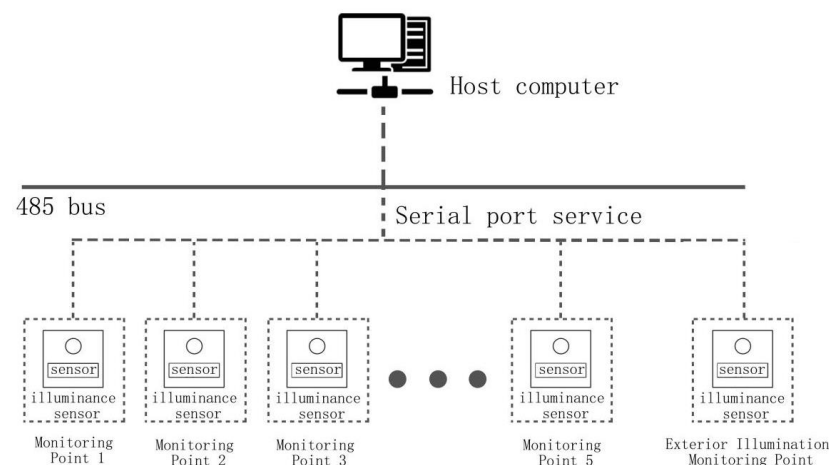


Figure 1. Composition of the illuminance acquisition system.

The post-finishing workshop in the clothing factory follows a process flow that involves various operations, including buttoning, ironing, sewing, and packaging of finished garments. Workers rotate positions based on their job responsibilities. The location of the illuminance sensor is illustrated in Figure 2.

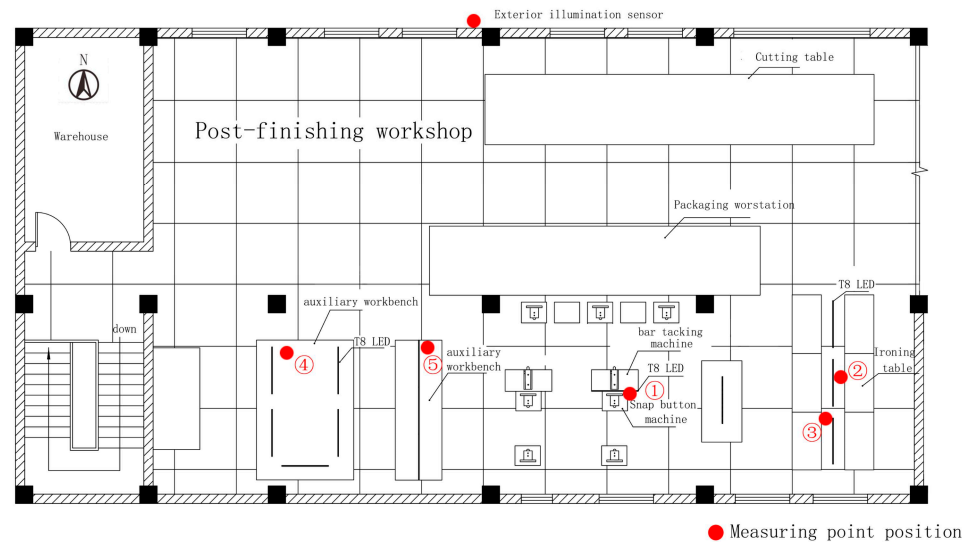


Figure 2. Layout of the illuminance sensors.

It is crucial to ensure that the illuminance sensor accurately captures the illuminance thresholds at the ironing table, auxiliary workstations, buttoning machine, and fastening machine. To prevent the movement of workers from interfering with the data cable of the exterior illuminance sensor, the sensor is mounted vertically on a bracket attached to the north side wall of the fourth floor. This positioning ensures that the sensor remains unaffected by the workers' activities, which primarily occur on the south side of the factory.

2.3. Experimental Procedure Design

The experiment was conducted over a period from 23 June 2022 to 2 June 2023. The working hours for the workers were typically from 8:00 to 11:30 and from 13:30 to 18:00. However, due to potential overtime work resulting from delays in the earlier stages of the project, the working hours occasionally extended from 8:00 to 12:00 and from 13:00 to 18:00. Throughout the experiment, illuminance data of the participants' work hours were recorded every minute to enable dynamic monitoring.

The initial phase of the study aimed to collect dynamic work surface illuminance data for a period of twenty days in the post-finishing workshop. This was conducted under the combined lighting method of side window lighting and localized illumination, with the objective of exploring the illuminance threshold of the work surface when the localized illumination was non-adjustable.

Subsequently, 24 subjects had T8 LED lamps installed at their workstations. These lamps were adjustable in terms of brightness and color temperature, with options of 3000 K, 4000 K, and 6500 K. The subjects connected their lamps to their smartphones via Bluetooth and adjusted the brightness and color temperature according to their individual needs and preferences. This was carried out to investigate the illuminance threshold of the work surface as desired by the workers in a dimmable lighting environment.

To minimize accidental errors during the experiment, the work surface illuminance data were collected from the subjects after one week of instructing them on lamp adjustment. The experiment was conducted from 19 July 2022 to 2 June 2023.

In the experiment, the illuminance sensor recorded the work surface illuminance every minute. To ensure effective data extraction, surveillance cameras were installed in the post-finishing workshop, and the illuminance data were subsequently extracted by analyzing the surveillance videos. The data were classified based on different color temperatures. Since

the experiment took place in a real working environment, the work surface illuminance of the subjects could occasionally be influenced by the lamps at neighboring workstations. Therefore, further classification of the illuminance data was conducted based on the number of lamps.

Only the illuminance data collected while the subjects were actively working at their workstations were included in the analysis. Data collected after the subjects left their workstations were excluded. Through surveillance observation, it was noted that the subjects did not adjust the lamp brightness when working for a short period of time. Therefore, illuminance values collected during work periods of less than 20 min were considered invalid. Data collected when the illuminance sensor was obstructed by fabric were also deemed invalid.

Given that the frequency of snap button machine usage during the experiment was not high, as it varied depending on the type of clothing being produced, this study focused solely on the illuminance threshold requirements of workers for the auxiliary workbench, ironing tables, and bar tacking machine.

3. Appropriate Illuminance Threshold

3.1. Lighting Environment Data Analysis

3.1.1. The Analysis of Data in the Non-Dimmable Lighting Environment

During the one-year illuminance monitoring, there were months when workers took leave or rest at the beginning or end of the month. To ensure consistent data collection intervals for exterior illuminance each month, the data points were extracted every hour during the mid-month period. This approach, as shown in Figure 3, helps maintain a similar time interval between data points for exterior illuminance throughout the year. By implementing this method, the accuracy and comparability of the collected data are ensured. From the monthly exterior illuminance data, it can be observed that the illuminance levels exhibit an upward trend during the summer, start to decline in autumn, and begin to rise again in spring. The exterior illuminance typically increases from 8:00 in the morning, reaches its peak around 1:00 in the afternoon, and then decreases. The variations in exterior illuminance are more pronounced during the spring season compared to other seasons.

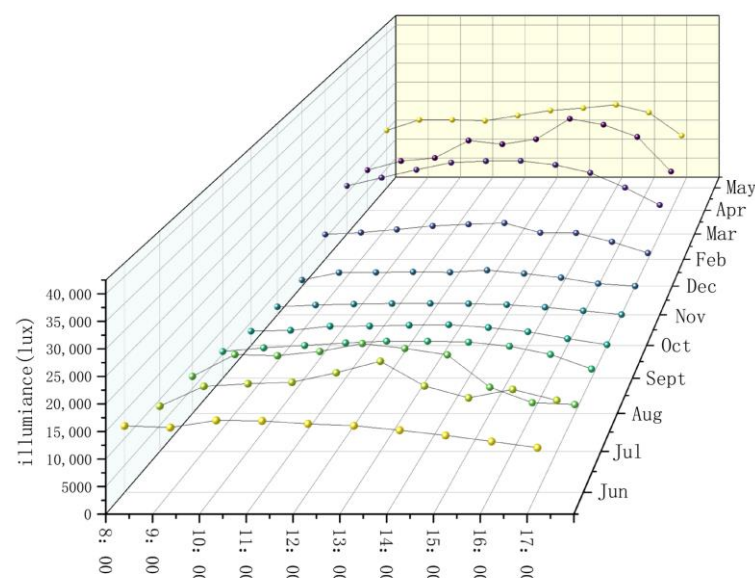


Figure 3. Exterior illuminance.

In the non-dimmable lighting environment, a day with relatively stable exterior illuminance was selected, and the illuminance at each monitoring point was recorded. The data collection interval was one hour, as depicted in Figure 4, which illustrates the relationship between indoor and exterior illuminance. Due to the combined lighting method of side

window lighting and localized illumination in the post-finishing workshop, the illuminance at each workstation is influenced by the exterior illuminance. Monitoring Point 2 and Monitoring Point 3 are most affected by the exterior illuminance, followed by Monitoring Point 1, while Monitoring Point 4 is least affected.

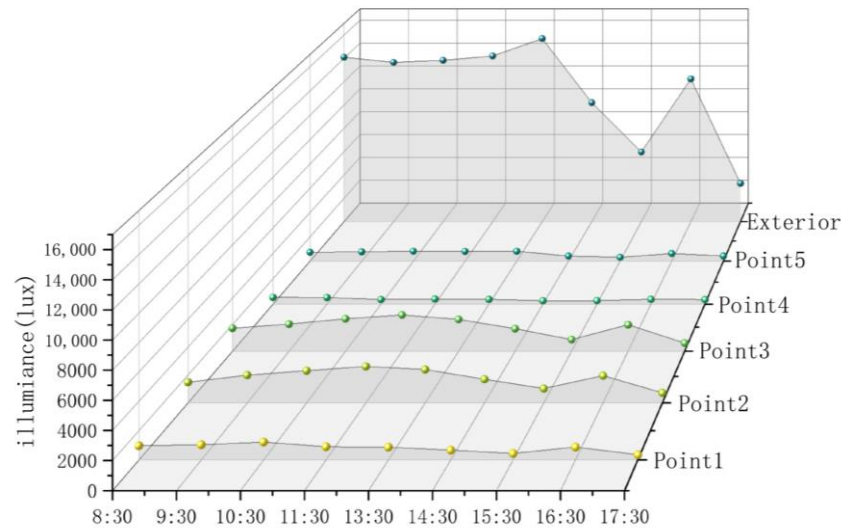


Figure 4. Relationship between exterior illuminance and indoor illuminance in the non-dimmable lighting environment.

Considering that workers in the post-finishing workshop change positions according to the process flow, data from each monitoring point in the non-dimmable lighting environment were collected four times per hour during working hours, with a time interval of 15 min, as shown in Figure 5. Due to the varying positions of each workstation, the exterior illuminance affects the range of illuminance distribution at each workstation. The illuminance on the indoor work surface is directly influenced by the exterior illuminance, resulting in an unstable illuminance level on the work surface. Working in environments that are excessively bright or dim can have a negative impact on workers' work efficiency and visual comfort. Unstable illuminance levels can interfere with workers' visual abilities, thereby affecting product quality [27].

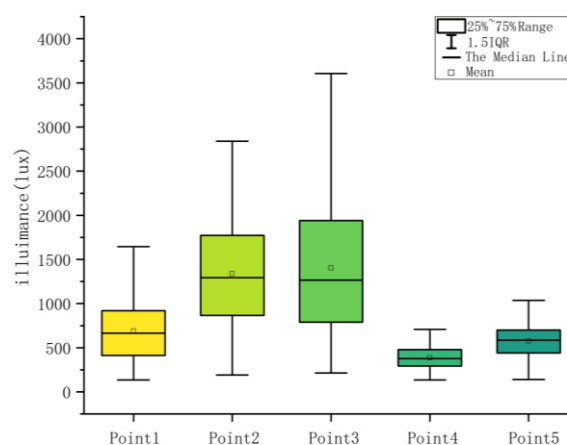


Figure 5. Illumination threshold of each point in non-dimmable light environment.

3.1.2. Analysis of Dimmable Lighting Environment Data

The illuminance data in the dimmable lighting environment were categorized and analyzed based on different color temperatures, as well as the influence of different lamps on the illuminance sensors. The categorization and analysis results are presented, respectively, in Tables 1 and 2.

Table 1. Lamp color temperature at 6500 K sensor illumination value.

6500 K	Min–Max (lux)	Mean (lux)	Median (lux)	Standard Deviation (lux)
Point 1	404–1101	709.61	711	150.46
Point 2	695–1458	1084.02	1102	162.02
Point 3	719–1344	1030.83	1023	137.89
Point 4	400–695	532.98	533	68.04
Point 5	507–909	757.31	764	80.88
Point 2 is affected by two lamps	1250–2406	1661.74	1628	209
Point 3 is affected by two lamps	1110–1998	1487.39	1472	137.89

Table 2. Lamp color temperature at 4000 K sensor illumination value.

4000 K	Min–Max (lux)	Mean (lux)	Median (lux)	Standard Deviation (lux)
Point 1	894–1927	1298.18	1259	215.42
Point 2	1314–2460	1833.72	1829	286.42
Point 3	1231–2205	1586.52	1568	193.45
Point 4	579–1239	802.14	782	117.95
Point 5	850–1929	1197.98	1167	215.48
Point 2 is affected by two lamps	1706–3740	2702.82	2666	408.07
Point 3 is affected by two lamps	1712–3577	2579.31	2536	442.54

When using T8 LED lamps with a color temperature of 6500 K, the maximum value at Point 2, which is influenced by two lamps, exceeds the average value by more than three standard deviations. Similarly, when using T8 LED lamps with a color temperature of 4000 K, the maximum data values for Points 3, 4, and 5 exceed the average value by more than three standard deviations. This indicates significant fluctuations in the data, suggesting that using the median as a measure of central tendency is more suitable than the average value. Considering the substantial data fluctuations, this paper will further subdivide the illuminance data.

Kernel density estimation, originally proposed by Rosenblatt [28] and Emanuel Parzen [29], consists of parametric and non-parametric estimation methods. Parametric estimation methods involve calculating the parameters of a known probability density distribution function using sample data, allowing for the calculation of the probability density value for a given test point. However, in practical applications, it is often challenging to determine the specific type of probability density function in advance, and therefore, non-parametric estimation methods are commonly employed. In this study, the illuminance data was subdivided by season, and the Gaussian normal kernel density formula was used to calculate the kernel density values, as illustrated in Figure 6.

From the peak values at each point, it can be observed that the subjects' illuminance requirements for indoor workstations are inversely proportional to the exterior illuminance. As the exterior illuminance decreases, the illuminance requirements for the workstations increase. In autumn, when the exterior illuminance decreases, the illuminance requirements for the workstations are higher compared to summer. Conversely, in spring, when the exterior illuminance increases, the illuminance requirements for the workstations decrease compared to winter. The illuminance range at Point 4 shows minimal variation with seasonal changes, which may be attributed to minimal influence from outdoor light at this specific point.

In this paper, the illuminance data was further divided, and kernel density calculations were performed based on different time periods and seasons. The peak values at each point were extracted, as depicted in Figure 7. This provides a reference for determining the illuminance requirements of indoor work surfaces in smart buildings.

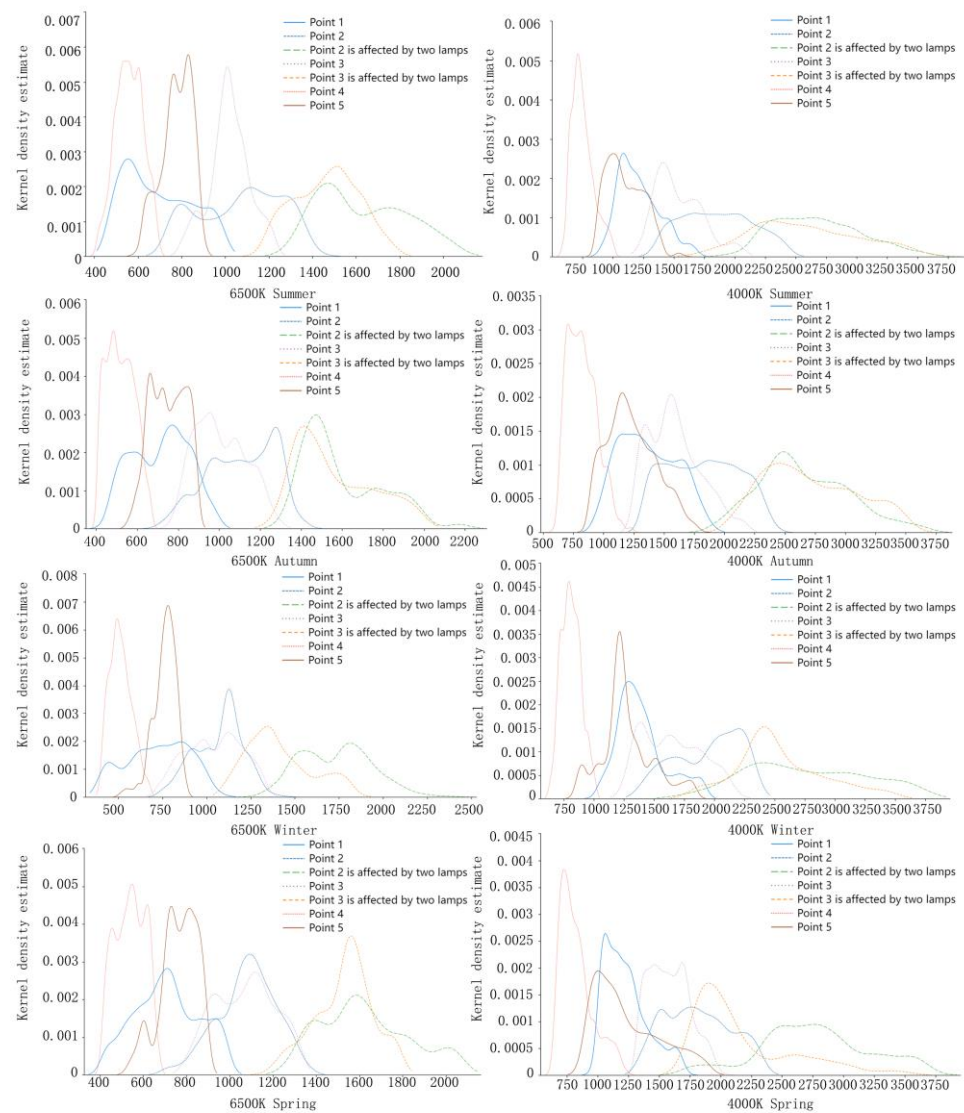


Figure 6. Kernel density estimates for different seasons and color temperatures in dimmable light environments.

During different time periods within the same season, the subjects adjusted the illuminance at each workstation to avoid excessive contrast between the workstation and the background brightness. The illuminance at each workstation would change with variations in exterior illuminance.

Two months after conducting the dimmable lighting experiment, interviews were conducted with the subjects to minimize any potential experimental errors resulting from inadequate experimental design. The interview questions are listed in the Table 3.

Table 3. Interview Question.

Interview Question
1. Which do you prefer, dimmable lighting or non-dimmable lighting?
2. Did you find any difficulties or challenges in adjusting the illuminance at your workstation during the dimmable lighting experiment?
3. Does the brightness of the dimmable lamp meet your work requirements?
4. Which color of light do you prefer at work? Why?

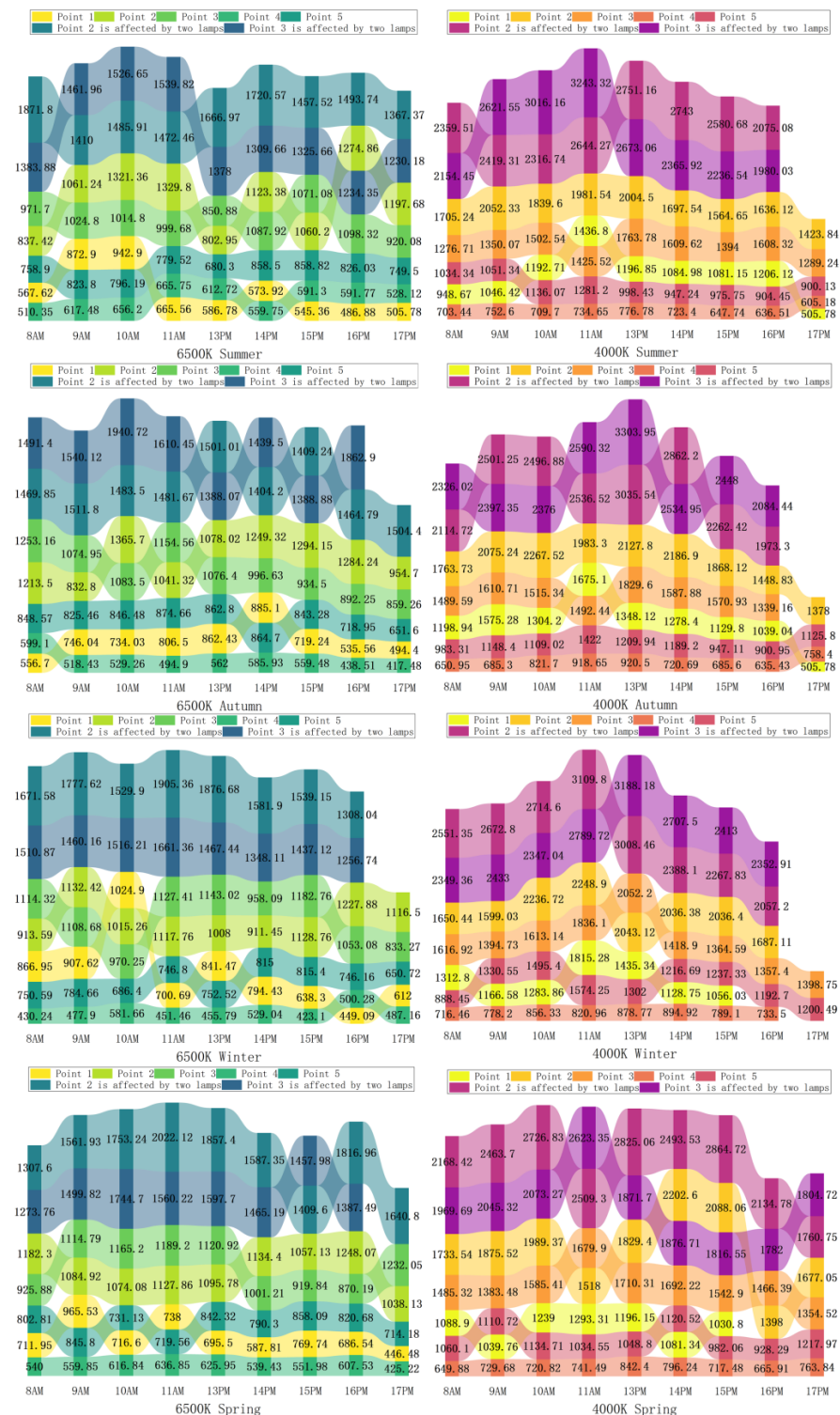


Figure 7. The kernel density peak value of color temperature of illuminance sensors in each season and period under dimmable light environment.

The subjects expressed a preference for dimmable lighting fixtures as they allowed them to adjust the illuminance according to their preferences. They found that the illuminance provided by the lamps met their work requirements. Regarding color temperature, the subjects leaned towards choosing a color temperature of 6500 K. They believed that higher color temperatures enhanced visual clarity and were particularly useful when working with fabrics of different colors, as they provided better color reproduction. When the

illuminance exceeded their needs, the subjects preferred not to change the illuminance but instead adjust the color temperature to 4000 K. Conversely, when the illuminance was insufficient, they would adjust the color temperature to 6500 K to enhance visual clarity.

During the experiment, none of the workers used lamps with a color temperature of 3000 K. However, during the initial week of learning to adjust the lamps, one worker used lamps with a color temperature of 3000 K. Upon interviewing this worker, she explained that she used the 3000 K lamps because she was not yet familiar with adjusting the lamps. They found the lighting environment to be particularly dark and felt that it negatively affected their visual clarity and work progress.

4. Lighting Layout Optimization

4.1. Calculation Model for Linear Light Source Illuminance

When considering a linear light source as being composed of numerous point light sources, we can establish a spatial Cartesian coordinate system with the work surface. In this space, there is a linear light source with a luminous flux of ϕ , a length of l , and a distance from the work surface height of h . A and B represent the two endpoints of the linear light source, while P represents a moving point (x_p, y_p, h) on the linear light source AB, as illustrated in Figure 8. The illuminance of the linear light source AB on a specific point on the work surface can be calculated using the formula:

$$\cos \alpha = \frac{h}{d}$$

$$d = \sqrt{(x - x_p)^2 + (y - y_p)^2 + h^2}$$

$$E = \frac{\phi h}{4\pi} \int_x^{x+l} [(x - x_p)^2 + (y - y_p)^2 + h^2]^{-\frac{3}{2}} dx_m \quad (1)$$

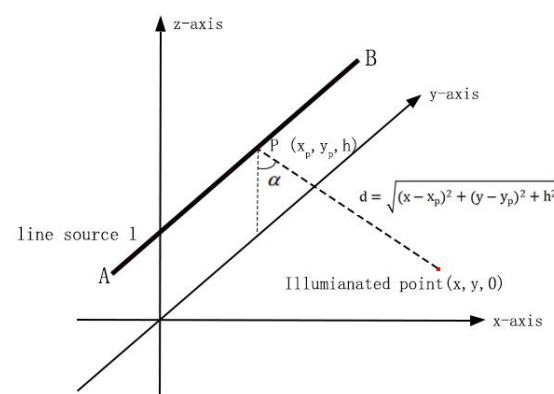


Figure 8. Schematic diagram of line light source illuminance calculation.

4.2. Appropriate Illuminance Threshold

This paper categorizes the lighting layout in the post-finishing workshop into three scenarios based on the production processes: lockstitch machine, auxiliary workbench, and ironing station. Specifically, the auxiliary workbench is simplified as a 600 mm $\times$ 1200 mm working surface, as shown in Figure 9.

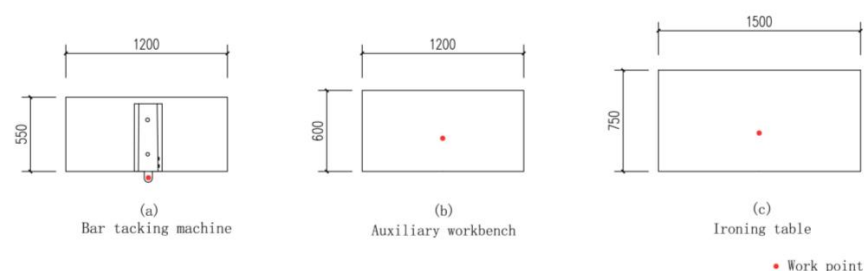


Figure 9. Three scenarios based on the production processes.

The illumination threshold for the workers' workstations was calculated by estimating the peak illuminance values using Formula (1) for different seasons and time periods in the autonomous dimming experiment. The results are shown in Figure 10, providing a reference for the illuminance of indoor work surfaces in smart buildings.

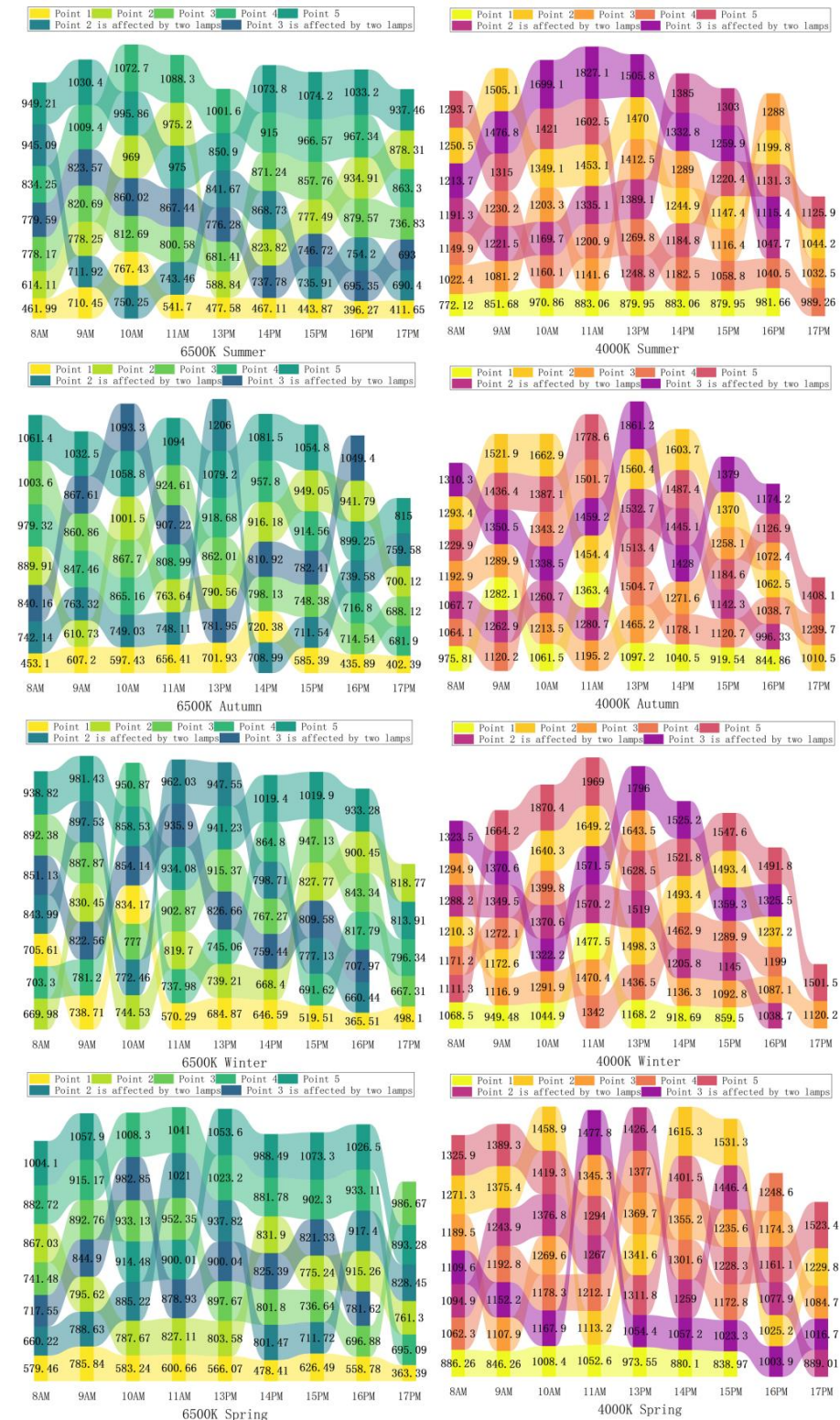


Figure 10. The kernel density peak value of color temperature of work point in each season and period under dimmable light environment.

4.3. Suitable Height for Luminaire Placement

Considering the current situation where the lighting fixtures in the clothing production workshop cannot be dimmed, it is necessary to determine the appropriate height for the placement of the lamps. This will serve as a reference for the layout of lighting fixtures in the workshop. Based on the workers' preference for a color temperature of 6500 K observed during the preliminary experiments, and considering the economic costs in the clothing production workshop, kernel density estimation was performed on the illuminance data collected over one year at a color temperature of 6500 K. The results are illustrated in Figure 11.

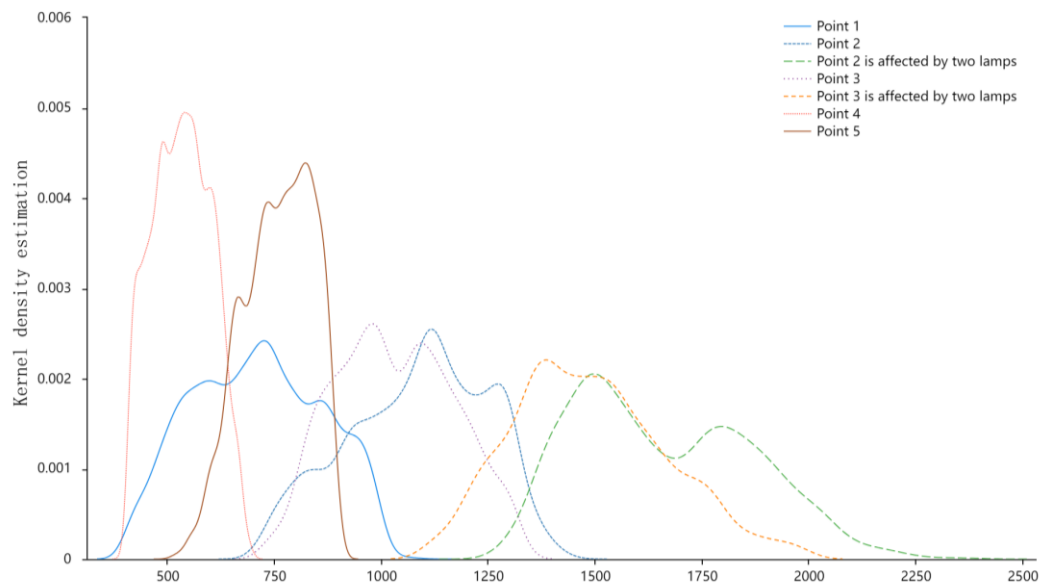


Figure 11. The kernel density peak value of illumination of work points under adjustable light environment.

Although some of the data loggers are used for the same job type, variations in the collected illuminance data can occur due to the different placement positions of the illuminance sensors. To mitigate this issue, the peak value of each data collection point is extracted, and Equation (1) is utilized to calculate the illuminance values at the workers' working point. The results are presented in Table 4. According to the GB 50034-2013 standard [30] for architectural lighting design, the illuminance at the workers' workstations should be 300 lux. However, the workers' demand for illuminance exceeds the standard requirement.

Table 4. The illuminance of each collection point and the working point illuminance.

Position	Point 1	Point 2	Point 2 Is Affected by Two Lamps	Point 3	Point 3 Is Affected by Two Lamps	Point 4	Point 5
Illumination of collection point (lux)	724.62	1114.65	1504.32	975.25	1385.28	541.6	816.54
Working Point Illumination (lux)	589.77	817.42	759.54	781.01	780.38	885.33	1021.3

To account for real-world scenarios where workbenches are often arranged side by side, and adjacent lamps can impact the illuminance experienced by workers, the three initial scenarios are further divided into nine situations. These situations are depicted in Figure 12. Scenario (1) represents individual placement, where only one lamp influences the workstation. In the case of workstations arranged side by side, the lamps on the sides affect the adjacent workstations, while the middle workstation is influenced by lamps on

both sides. The range of heights for placing the lighting fixtures is determined based on these nine situations.

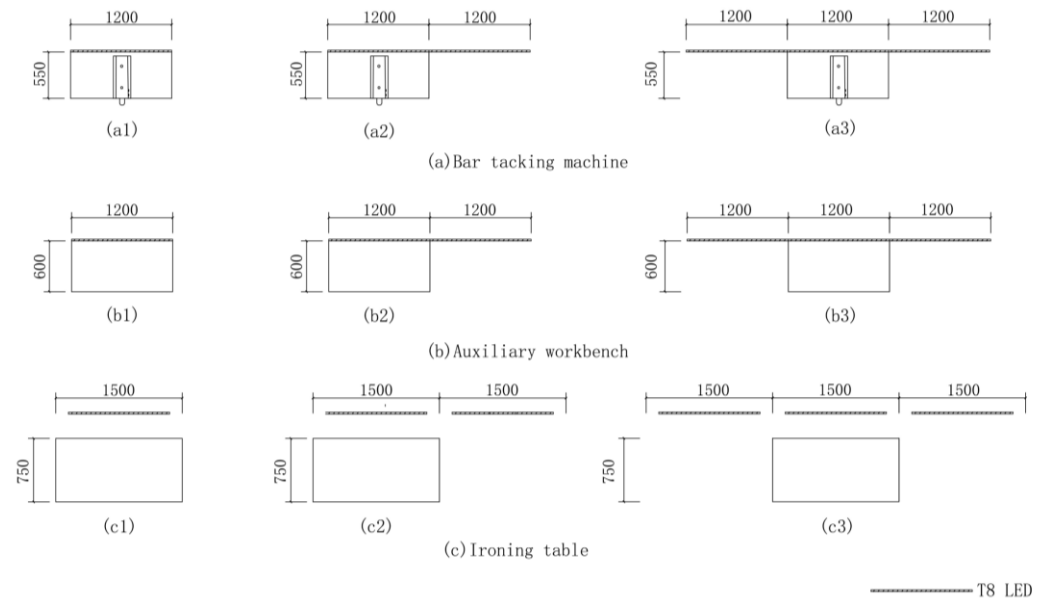


Figure 12. Lighting situation in the post-finishing workshop.

We opted for T8 LED lights with a color temperature of 6500 K, power of 16 W, and luminous flux of 1000 lm. By using Formula (1) and taking into account the illuminance thresholds at seven distinct points, we determined the suitable heights for the lighting fixtures at the bar tacking machine, auxiliary workbench, and ironing table for nine different layouts. However, for the ironing station, the illuminance requirements of the workers could not be fulfilled with a 1000 lm lamp, so we calculated the height based on a 1500 lm lamp instead. The results are presented in Table 5:

- (1) Represents the height of individual placement for each workstation.
- (2) Represents the height of the lamp arrangement at both ends of the workstations when arranged side by side.
- (3) Represents the height of the lamp arrangement for the middle workstation when arranged side by side.

Table 5. Height of each collection point.

	Point 1	Point 2	Point 2 Is Affected by Two Lamps	Point 3	Point 3 Is Affected by Two Lamps	Point 4	Point 5
(1)	0.9 m	0.57 m	0.78 m	0.73 m	0.73 m	0.78 m	0.68 m
(2)	1.28 m	1.08 m	1.2 m	1.15 m	1.16 m	1.02 m	0.89 m
(3)	1.68 m	1.49 m	1.61 m	1.56 m	1.56 m	1.29 m	1.13 m

Illuminance uniformity refers to the level of consistency in the distribution of illuminance across a given area. In the context of work surface illuminance, uniformity is determined by calculating the ratio of the minimum illuminance value to the average illuminance value on the work surface. As the illuminance threshold varies for different workstations and the heights of workbenches differ, illuminance uniformity serves as an optimization criterion for optimizing the placement of light sources.

To consider the mutual influence of adjacent lamps and calculate the illuminance uniformity for each workstation separately, a for loop statement is used in MATLAB. Based on the height ranges for the bar tacking machine, auxiliary workbench, and ironing table lighting fixtures, the uniformity is calculated for the nine layout scenarios. The calculation process follows the flowchart shown in Figure 13.

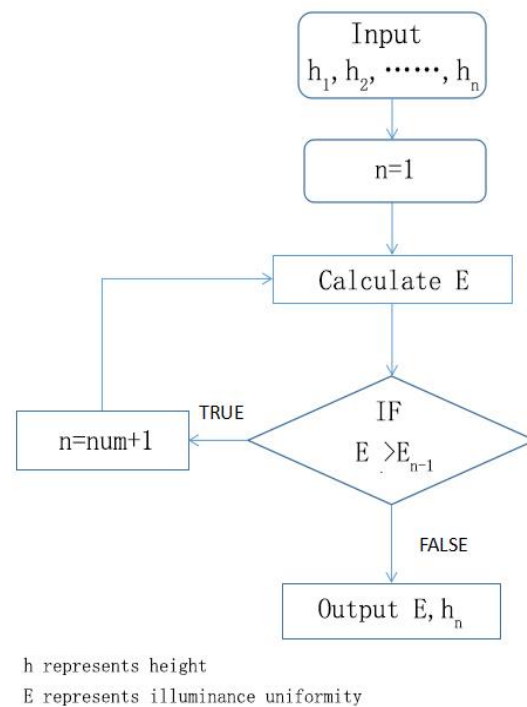


Figure 13. Flow chart.

Starting from the minimum value of the height range, the uniformity is calculated for each step increase of 0.01 m in the height. The calculation continues until the maximum uniformity or maximum height is reached. By iteratively calculating the uniformity for different heights within the specified range, the optimal height for achieving the desired illuminance uniformity can be determined.

When the workbench is arranged individually, it has been observed that higher heights lead to greater illuminance uniformity. Based on this finding, the optimal height for the lighting fixture at the bar tacking machine is determined to be 0.9 m, while for the auxiliary workbench and ironing table, it is 0.78 m.

In the case of workbenches arranged side by side, it is important to ensure that the illuminance uniformity of the middle workstation is higher than that of the end workstations. To achieve this, the optimal height for the lighting fixture at the bar tacking machine is 1.28 m, for the auxiliary workbench is 1.02 m, and for the ironing table is 1.2 m.

To optimize economic costs, it is possible to choose lighting fixtures with lower luminous flux for the middle workstation, as long as the illuminance requirements are still met. This allows for cost savings while ensuring adequate illuminance for the workers. The appropriate illuminance for the bar tacking machine is 589.77 lux. The illuminance for the auxiliary workbench should be 885.33 lux, while the illuminance for the ironing table should be maintained at 759.54 lux.

5. Discussion

Ensuring a favorable illuminance environment in a factory setting presents a complex research challenge. Researchers must conduct their studies without disrupting the progress of workers' tasks while still obtaining reliable and meaningful conclusions. Moreover, lighting conditions in a factory comprise a combination of natural and artificial light, with the distribution, intensity, and spectral composition of light changing throughout different times and seasons.

In this study, the experiments conducted in this study focused solely on the effects of illuminance and color temperature, with minimal worker intervention. However, it is important to recognize that glare is a significant factor that affects visual comfort and should be considered in future experiments. The potential occurrence of glare resulting

from windows in the workspace was not considered. Furthermore, when optimizing the placement of lighting fixtures, it is advisable to select fixtures with lower luminous flux. However, careful attention should be given to the height at which these fixtures are installed. This is crucial to prevent the occurrence of glare in the workers' visual work areas.

Further aspects that was not addressed in this research are the non-visual effects of light. Natural light has been found to have more positive effects on circadian rhythm and mood regulation compared to artificial light. However, the effective utilization of natural light is often hampered by glare. Enhancing the utilization of natural light and improving the quality of the lighting environment pose significant challenges, especially in achieving more efficient utilization of natural light with lower investment.

It is crucial to acknowledge that the study discussed in this research paper concentrates on establishing suitable illuminance thresholds specifically for female employees. However, it is worth considering that male employees, if included as research subjects, may exhibit distinct threshold preferences and requirements. If the sample of participants encompassed male workers as well, variations in the results could be observed. It is plausible that the preferred illuminance threshold for males might be higher compared to that for females. Therefore, future studies should consider the inclusion of male employees to obtain a comprehensive understanding of illuminance preferences across different genders.

6. Conclusions

This study addresses the issue of insufficient illuminance on work surfaces in the finishing workshop of a clothing factory. To tackle this problem, adjustable lighting fixtures with variable brightness and color temperature were installed, allowing workers to personalize the lighting based on their preferences. A dynamic monitoring of work surface illuminance was conducted over the course of one year. Considering the specific requirements of different process flows in the workshop, the study explores the appropriate illuminance thresholds and color temperature preferences of workers, ultimately optimizing the layout of light sources.

In anticipation of future smart building applications, this study further subdivides the illuminance thresholds based on seasons and time, providing valuable insights for such implementations. Furthermore, the lighting layout for the three distinct process flows in the finishing workshop was also subdivided. By utilizing illuminance uniformity as an optimization criterion, the optimal heights for lighting fixtures were determined as follows: 0.9 m for the bar tacking machine, 0.78 m for the auxiliary workbench, and 0.78 m for the ironing table when the workbenches are arranged individually. For workbenches arranged side by side, the optimal heights are 1.28 m for the bar tacking machine, 1.02 m for the auxiliary workbench, and 1.2 m for the ironing table. The appropriate illuminance for the bar tacking machine is 589.77 lux. The illuminance for the auxiliary workbench should be 885.33 lux, while the illuminance for the ironing table should be maintained at 759.54 lux.

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