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Investigating the Impact of Combined Daylight and Electric Light on Human Perception of Indoor Spaces

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Abstract: People spend more than 90% of their time indoors, and, as such, improving indoor lighting quality can enhance their quality of life by positively influencing both physiological and psychological aspects. Numerous studies suggest that perceptions of a space vary depending on a number of lighting attributes present. Significant effort has been made across various fields to identify the spatial lighting conditions and attributes that impact human perception, although we lack studies that explore the impact of these conditions in tandem. This paper investigates how interior lighting conditions influence human impressions of room ambiance. The study examines 16 different interior scenes, considering factors such as sky condition (sunny vs. overcast), shading blinds position (open vs. closed), presence or absence of electric light (on vs. off), and Correlated Color Temperature (CCT) (2700 K, 4000 K, and 6500 K). The evaluation is conducted within an office environment at Carnegie Mellon University, using a combination of objective lighting metrics and subjective assessments. In total, 26 participants, consisting of 11 females, 14 males, and one undisclosed, aged between 18 and 50, evaluated the office ambiance under various lighting conditions using semantic differential scales. The analysis showed that the variation of blinds and CCT levels significantly influenced the participants' impression of light. The study also identified statistically significant interactions between "blinds and CCT" and "blinds and sky" conditions, highlighting the combined influence of these variables on shaping indoor light impressions. This research offers valuable insights into the complex interplay of different lighting factors in shaping human perceptions, and underscores the importance of optimizing indoor lighting conditions for creating healthy and sustainable indoor environments.

Keywords: indoor lighting; human perception; daylight; electric light; CCT; blinds

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1. Introduction

Creating healthy and comfortable living and working spaces for occupants is a pillar of sustainable building practices [1]. Sustainable buildings aim to provide quality indoor environments that enhance the well-being of their inhabitants while reducing the building's negative environmental impacts [2–4]. Central to this practice is indoor lighting, which has a significant impact on both human psychology and physiology [5–7]. Green building and lighting standards have increasingly emphasized optimizing daylight and supplementing it with electric light, ensuring well-lit environments to improve task performance and visual comfort [8,9]. While providing adequate light in space is necessary, several works suggest that the influence of light on humans is profound. Past research shows that visually pleasing luminous environments create positive effects that improve human mood, work engagement, social cooperation, performance, etc. [10]. Multiple research studies show that people may have different impressions of light attributes like brightness, uniformity, patterns, color temperature, etc. [11–13]. People also relate spatial lighting conditions to different perceptions of "calming", "spaciousness", "interesting", etc. [14].

The influence of various light metrics such as illuminance, luminance, and CCT on human impression of light is explored across different fields [15–18]. Within the field of architecture, researchers have explored the relationship between daylight levels in buildings and occupant satisfaction. Numerous studies have indicated a clear correlation between occupant satisfaction, productivity, and well-being, and both daylight exposure and access to external views [7,19,20]. The work in this area is not limited to exploring only daylight accessibility and exposure. In a Virtual Reality (VR)-based study on 100 participants, Sawyer et al. demonstrated that in rooms with identical brightness levels elicited different impressions of light and spatial brightness due to distinct façade patterns [21]. Similarly, Chamilothori et al., in multiple papers, have demonstrated the relationship between shadow patterns, daylight exposure, and their influence on human physiological responses, such as heart rate [12,22,23]. Their findings showed that participants rated façades with irregular patterns as more interesting, and the recorded mean heart rate was shown to be slower when exposed to irregular patterns compared to the other patterns studied.

Several studies have established connections between various attributes of electric light such as CCT and illuminance and human perception. For instance, Chen et al. and Müezzinoglu et al. conducted studies indicating that individuals experienced greater positivity and comfort under lower CCT levels compared to higher CCT values [15,24]. Other studies have indicated a more complex relationship between light CCTs and human impressions and mood. For instance, in a study conducted by Zeng et al., participants were exposed to four different CCT values: 4000 K, 6000 K, 8000 K, and 10,000 K, while performing two types of tasks. The findings showed that participants felt more comfortable but sleepier under lower CCT values, while they felt more productive but less comfortable under higher CCT values such as 6000 K [25]. It is important to note that these studies were conducted in the absence of daylight and did not account for the interactions between different light sources such as daylight/sky and electric lights.

While studies have explored the combination of daylight and electric light, they have primarily concentrated on visual comfort, overlooking the evaluation of various ambiances created under these lighting conditions and limiting the range of tested perception categories [5]. On the other hand, some studies have compared daylit to artificially lit office settings and how they influence people's mood and visual comfort [26]. In a comprehensive literature review of papers exploring the relationship between indoor lighting and human perception spanning from 1973 to 2022, the authors identified 64 relevant articles, with only 3 papers addressing both daylight and electric light [27]. However, these studies compared daylight and electric light and did not study their combined effects [6,27,28].

The small number of papers on this area suggests a significant gap in the literature regarding human impressions of indoor lighting. Most studies investigating the impact of lighting conditions on the perceived quality of indoor spaces can be grouped into two categories: those conducted in laboratory settings [24,25,29], and those conducted in virtual settings [30–33]. In both settings, electric and natural light are often studied separately to ensure controlled research conditions. As a result, these setups may not accurately represent the lighting conditions experienced in everyday spaces, where indoor lighting consists of a combination of daylight and electric light that dynamically changes throughout the day. Moreover, these experiments overlook the complex interactions and dynamic variations between different light sources, as well as the lighting conditions that emerge from human interaction with lights and adjustments in blind positions (opening or closing).

It is important to highlight the limited research currently available on how various factors contributing to indoor lighting influence people's impressions and preferences. For example, it remains unclear whether people's preference for light CCT is affected by the presence or absence of daylight or different sky conditions. Similarly, while existing research supports the positive effects of daylight on mood [26] and explores the benefits of blinds in terms of visual comfort and privacy [34], it is still unclear how people's preference for the position of blinds may change when electric lights and sky conditions are considered. Therefore, it is necessary to conduct research that investigates the combined impact of daylight and electric light on human perceptions of space in real-world settings. Such studies will enable us to develop a more accurate understanding of how light influences visual interest and preferences.

2. Materials and Methods

The study setup leveraged both subjective feedback and controlled lighting variations, assessing the influence of indoor lighting on human perception. The experiment explored sixteen distinct lighting setups varying in (1) electric light presence (lights on vs. off), (2) blinds position (open vs. closed), (3) sky condition (sunny vs. overcast), and (4) CCT (2700 K, 4000 K, and 6500 K). A custom LED setup was employed to create these lighting conditions within an office space. Twenty-six participants, randomly recruited, rated the lighting conditions through structured questionnaires using seven-point semantic differential scales on impressions of ″Coziness″, ″Tenseness″, ″Impersonality″, ″Calming″, ″Exciting″, ″Likability″, ″Productive″, ″Monotonous″, and ″Vibrant″. Various statistical analysis tests, such as Analysis of Variance (ANOVA), and non-parametric tests like the Friedman and Kruskal–Wallis tests, were used to assess the individual and joint influence of the independent variables on each tested lighting perception. The following provides a detailed explanation of the study setup and procedure.

2.1. Location

As part of this study, a small meeting/office space at the Carnegie Mellon University's campus in Pittsburgh was selected as a case study. This space is used daily by students and faculty members at the university for work and study related tasks. The space was chosen for this study to replicate realistic lighting conditions commonly encountered in daily settings. The room features east-facing windows and receives ample daylight. The window has white roller shades. The dimensions of the room are 13 by 10 ft (3 by 4 m), with a ceiling height of 9.5 ft (3 m). The wall shared with the hallway is fully glass, while the front and one side wall are white, and the northern wall is blue. The room is furnished with a white desk, a wall-mounted TV, and a whiteboard. The carpet is dark gray. The light fixture is positioned 12 inches (30 cm) below the ceiling.

2.2. Lighting Conditions

For the experiment, a total of 16 different lighting conditions were evaluated. One set of conditions was examined under sunny sky conditions, while the other set was examined under overcast sky conditions. For each sky condition, lighting conditions were created with the lights turned on and off, and with the blinds both open and closed. Additionally, under each lighting condition where the lights were turned on, three different types of color temperature were tested: warm (2700 K), neutral (4000 K), and cool (6500 K). Figure 1 shows the lighting conditions created on each day of the experiment.

The study necessitated a lighting setup enabling the manipulation of the light switches and the adjustment of CCTs throughout the experiment. However, the existing lighting configuration in the space did not meet these criteria. As the space is heavily used and regularly occupied, and due to university restrictions on changing lighting fixtures or bulbs, it was not possible to replace the existing fixtures. In response to these limitations, a custom light fixture was devised to create various lighting configurations in the experiment by augmenting LED lights onto the existing fixtures (6 feet by 2.5 inches (1.8 m by 6.5 cm)). A total of 36 feet (approximately 11 m) of LED strip lights were used to achieve different lighting conditions by providing direct and indirect lighting. In this experiment, LED strips were strategically placed to enhance lighting conditions. The Paltrix CCT COB strip lights, featuring a Rated Power of 2.14 w/ft and an Adapter Rated Power of 24 V 1.5 A (36 W), were used for this purpose. To achieve optimal diffusion, the bottom LED was covered with two layers of frosted film. Figure 2 illustrates the resulting lighting setup.

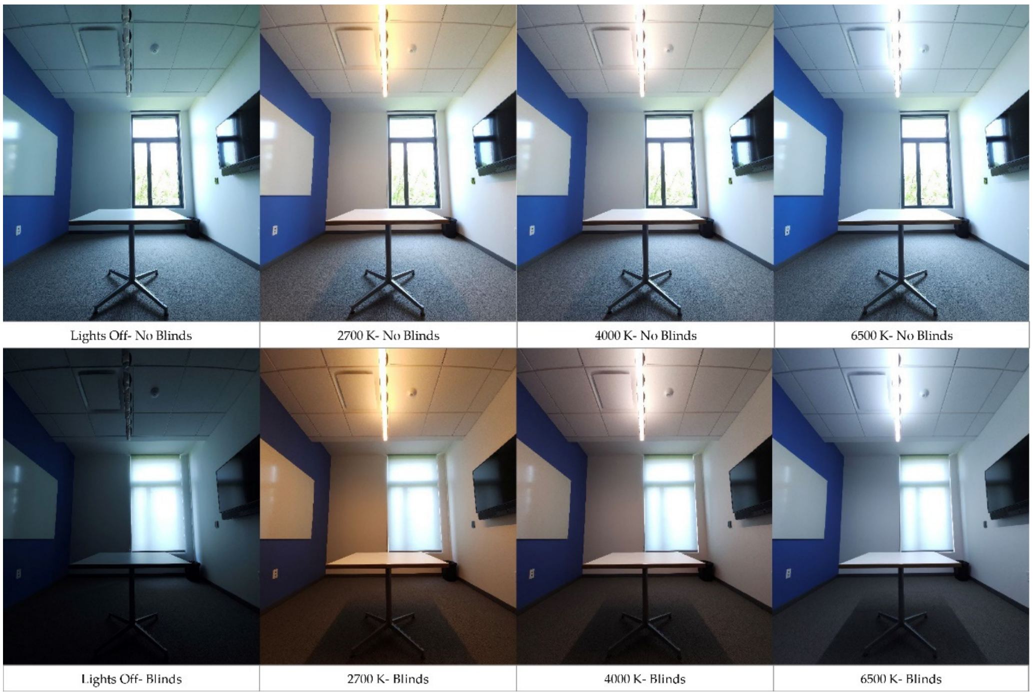

Figure 1. A total of eight unique lighting conditions were generated for each sky condition, incorporating variations such as open and closed blinds, lights turned on and off, and three different CCT values of 2700 K, 4000 K, and 6500 K.

Figure 2. Custom Light setup. LED lights were attached to the bottom of the room's existing light fixture (direct light) and were placed on top (indirect light).

2.3. Participant Recruitment and Ethical Approval

Participants were randomly recruited through various methods, including targeted emails sent to mailing lists of students, faculty, and staff at Carnegie Mellon University, as well as posts on social media platforms such as LinkedIn and in-person announcements in class. Participation was entirely voluntary and unpaid. Eligibility was limited to adults present in the study location. Participants had the option to withdraw from the study at any point during or after the experiment without incurring any penalties. A total of 35 participants took part in the study. Nine participants were only able to participate in one out of two study sessions, resulting in their responses being excluded from the analysis.

The analysis included responses from 26 participants, comprising 11 female, 14 male, and 1 participant who chose not to respond. The participants ranged in age from 18 to 50, with 13% aged 18–25, 71% aged 25–30, 12% aged 30–40, and 4% aged 40–50.

2.4. Experimental Procedure and Questionnaire Design

The experimental sessions lasted approximately 25 to 30 min each. Each participant evaluated the lighting conditions on two separate days, experiencing both sunny and overcast skies. Groups of 5–8 individuals were led into the room where they received a brief overview of the study's purpose: to gather their subjective feedback on the room's lighting. They were not informed about the specific lighting variations they would encounter. On the first day of the experiment, participants selected their seats, and the researcher noted each participant's seating location (see Figure 3). On the second day of the experiment, participants returned to the same seats, ensuring consistency in their experience across both sessions. On both days, participants accessed the study questionnaire by scanning a QR code with their phones. They then observed the room under each lighting condition and provided feedback through the questionnaire on their phones. Participants were instructed to record their responses individually and refrain from discussing or sharing their evaluations during the experiment. Throughout each session, an experimenter remained present, adjusting the electric light settings and operating the blinds to transition between different lighting configurations.

Figure 3. Left: experiment room floor plan (units in inches). **Right**: experiment room view.

The questionnaire consisted of two main sections: (1) general questions regarding the overall lighting conditions participants typically encounter during weekdays or work hours, and (2) questions specific to the experiment and the different lighting conditions tested. It is important to note that the analysis of the first section of questions falls beyond the scope of this paper and will be presented in future publications.

The questions for each lighting condition remained consistent, but they were shuffled to minimize repetition and survey fatigue. The questions related to each lighting condition are listed in Table 1. Participants were asked to rate the different lighting conditions using seven-point semantic differential scales. These scales were based on the dimensions of "Coziness", "Liveliness", "Tenseness", and "Impersonality", as proposed by Ingrid Vogels for quantifying perceived atmosphere [35]. Additionally, rating scales proposed by Flynn et al., such as "Calming", "Exciting", and "Likeability", were included [14]. Considering the office/work setting of the study, a "Productivity" rating scale was also included. To assess the level of variety and visual stimulation, rankings of "Monotonous" and "Vibrant" were included.

Table 1. Study questions and the relevant semantic differential scale.

Question	Scale (1 to 7)
Does the lighting create a cozy atmosphere in this space?	Not at all cozy–incredibly cozy
Does the lighting create a lively atmosphere in this space?	Not at all lively–incredibly lively
Would you say that the lighting in this space has a negative impact on your mood, specifically causing you to feel tense or anxious?	Not at all tense–incredibly tense
Does the lighting (in this space) create an impersonal or unfamiliar atmosphere?	Not at all impersonal–incredibly impersonal
On a scale of 1 to 7, how calming does the lighting in this space feel to you?	Not at all calming–incredibly calming
On a scale of 1 to 7, how much does the lighting in this space contribute to a feeling of excitement?	Not at all exciting–incredibly exciting
Would you feel alert and productive working under the lighting in this space?	Not at all alert–incredibly alert
On a scale of 1 to 7, how much do you like the overall lighting in this space?	Strongly disliked–strongly liked
Does the lighting feel monotonous to you?	Not at all monotonous–incredibly monotonous
On a scale of 1 to 7, how vibrant does the lighting in this space feel to you?	Not at all vibrant–incredibly vibrant

2.5. Lighting Measurements and Conditions

The experiment took place mid-May to mid-June 2023, between 11 am and noon, for each sky condition. The study was conducted over four different days consisting of two days with an overcast sky and two with a sunny sky. Illuminance was measured at all seat zones (1, 2, and 3) and the middle of the room where the desk is located, while CCT measurements were taken in the middle of the room. For each seat zone, Ev values were recorded at eye level (4 ft/1.2 m) for 180 degrees (0, 45, 90, 135, 180 degrees) and averaged for individuals seated in each zone with their backs against the walls. In zone 1, measurements were taken for individuals facing the window, whereas in zones 2 and 3, individuals faced the window to their left. Horizontal illuminances (Eh) and CCT were measured at desk level (30 in/77 cm). To control the effect of light entering the experiment room through the glass wall, the electric lights in the hallway were set to the minimum brightness level permitted by the building's system, leaving only one light on. This adjustment effectively minimized the influence of ambient light from the corridor to the experimental conditions within the room.

The LI-180 Licor Spectrometer (Lincoln, NE, USA) device was used for these measurements, and Table 2 presents the recorded data per day. As indicated by the recorded values in the table, the illuminance levels for the same lighting conditions and zones on different experiment days exhibit a maximum difference factor of 1.1, which falls below the threshold for a noticeable change in illuminance [36]. Therefore, variations in illuminance levels under the same lighting conditions and shared sky conditions are not expected to influence participant responses collected on separate days.

The study was conducted in the morning, coinciding with a time when the room received direct sunlight from the east-facing window. The decision to turn on the electric lights during the experiment was made to simulate typical room usage patterns, where occupants may augment natural daylight with artificial lighting to ensure adequate light levels for tasks. The experiment setup aims to capture these real-world conditions to understand how lighting choices may impact user experience and performance. As shown in Table 2, under various skies and with or without blinds, the room's illuminance levels (Eh) fell below the recommended range of 300–500 lux for office task performance. This suggests that additional lighting may be necessary to supplement natural daylight in the room, particularly on overcast days or when blinds are closed. Additionally, the ability to adjust the electric lights allows for flexibility in meeting users' preferences and needs. For instance, sunny days with open blinds, having the lights on may mimic common usage patterns where individuals choose to combine natural and electric lighting sources for optimal comfort and productivity. Overall, the experimental setup aimed to replicate the dynamic lighting conditions experienced in the room throughout the day and emphasizes the interaction between natural and electric lighting in real-world settings.

Table 2. Light measurements (Eh, Ev, and CCT) on experiment days.

	Lighting Condition	**Zone 1**		**Zone 2**		**Zone 3**		**Center**		
		Eh (lux)	**Ev (lux)**	**Eh (lux)**	**Ev (lux)**	**Eh (lux)**	**Ev (lux)**	**Eh (lux)**	**Ev (lux)**	**CCT (K)**
Sunny Day 1	Lights off-Blinds	109	119	110	122	125	127	122	125	5142
	6500 K-Blinds	589	204	455	209	472	232	632	212	5761
	4000 K-Blinds	576	194	435	199	435	229	615	203	4242
	2700 K-Blinds	581	200	443	205	448	226	624	205	3111
	Lights Off-No Blinds	348	280	336	288	369	320	380	340	5990
	6500 K-No Blinds	862	376	751	371	735	425	919	422	5855
	4000 K-No Blinds	844	367	728	359	710	412	882	415	4950
	2700 K-No Blinds	850	371	736	379	718	418	904	431	3933
Sunny Day 2	Lights off-Blinds	101	114	97	113	112	120	109	118	5134
	6500 K-Blinds	580	197	448	200	451	225	628	202	5700
	4000 K-Blinds	571	190	430	192	429	217	596	190	4180
	2700 K-Blinds	570	202	435	199	440	219	605	193	3130
	Lights Off-No Blinds	339	271	331	282	361	307	356	323	6020
	6500 K-No Blinds	851	362	740	360	725	412	893	414	5870
	4000 K-No Blinds	838	355	721	344	702	400	873	405	5000
	2700 K-No Blinds	845	360	729	370	715	406	887	416	3975
Overcast Day 1	Lights off-Blinds	22	40	18	40	32	72	27	45	5500
	6500 K-Blinds	450	131	320	129	320	168	502	129	5670
	4000 K-Blinds	435	117	294	115	288	148	468	115	3775
	2700 K-Blinds	442	124	312	120	312	150	480	122	2830
	Lights Off-No Blinds	104	148	90	157	125	192	121	202	6141
	6500 K-No Blinds	579	283	470	281	449	315	625	337	5777
	4000 K-No Blinds	562	260	445	252	429	282	605	315	4300
	2700 K-No Blinds	575	278	452	275	431	305	623	326	3833
Overcast Day 2	Lights off-Blinds	18	34	15	33	24	65	23	39	5134
	6500 K-Blinds	435	120	307	120	312	160	522	123	5640
	4000 K-Blinds	418	109	285	110	279	132	470	102	3730
	2700 K-Blinds	423	112	300	102	301	146	481	110	2850
	Lights Off-No Blinds	99	100	82	148	113	178	113	185	6100
	6500 K-No Blinds	573	270	460	274	436	301	619	325	5730
	4000 K-No Blinds	559	248	439	244	405	271	598	304	4350
	2700 K-No Blinds	564	269	440	265	418	296	615	320	3810

2.6. Data Analysis Method

A power analysis was conducted to determine the number of participants, considering the study's design conditions, such as the number of independent variables and each participant's evaluation of all tested lighting conditions. The G*Power software 3.1 [37] was used to determine the sample size for a three-way ANOVA with repeated measurements within factors. This aimed to achieve a power level of 80%, a level commonly recommended in social science research [38]. It indicates an 80% probability of correctly rejecting the null hypothesis when it is false, thereby reducing the risk of overlooking a true effect [39]. The analysis revealed that, with a significance level of $\alpha = 0.05$, a sample size of $N = 24$ is considered sufficient to detect a medium effect size of $f = 0.25$, according to Cohen's convention [40]. This calculated sample size confirms that the actual sample size for the study, which was 26, is suitable for the chosen statistical analysis.

The analysis aims to investigate the influence of different lighting conditions on participants' impressions of light. Specifically, the hypothesis is that there would be no significant differences in the average rating of each tested perception across different levels of independent variables, namely "CCT", "Blinds", and "Sky". This hypothesis was tested using a series of ANOVA tests to identify the influence of each independent variable and their interactions on the various impressions of the lighting scenarios. However, since the residuals of the data were not normally distributed, the results from ANOVA analysis need to be treated with caution. Therefore, the Friedman test was used to further explore how the combination of independent variables affects the responses. The Friedman test is a non-parametric alternative to repeated measures ANOVA, used when ANOVA's assumptions are not met. The Friedman analysis with Bonferroni correction examined the null hypothesis that the distribution of the response variable is the same across different conditions defined by the combinations of paired independent variables, such as "Sky-Blinds", "Blinds-CCT", and "Sky-CCT". For instance, in the case of the "Sky-Blinds" pair, the test assesses whether there are significant differences in the central tendencies of responses between the lighting scenarios divided into the four categories of "overcast sky-blinds closed", "sunny sky-blinds closed", "overcast sky-blinds open", and "overcast sky-blinds open". This analysis is helpful in identifying the influential combinations and interaction of variables in creating different ambiences/impressions in space.

For further analysis of the influence of the specific factors' levels on each mood response, a post hoc test, specifically Dunn's test with Bonferroni correction, was used. The post hoc test compared the differences within each factor, such as whether there was a difference between the presence and absence of "Blinds" in creating a specific ambiance within the room. The other compared pairs for the factors "Sky" and "CCT" were "sunny vs. overcast", "6500 K vs. 2700 K", "4000 K vs. 2700 K", and "6500 K vs. 4000 K".

In order to assess the effect of seat location on responses, a Kruskal–Wallis test, a non-parametric alternative to one-way ANOVA, was used to compare the responses in different seat zones. The null hypothesis stated that there is no statistically significant difference in the median of the responses among zones 1, 2, and 3. Similarly, a Kruskal–Wallis test was conducted to determine the effect of age on lighting impressions, with the null hypothesis stating that there are no statistically significant differences in the response medians among participants in different age groups. Given that only one participant falls within the 40–50 age range, the 30–40 and 40–50 age groups were merged into a single category, resulting in three distinct age groups for comparison: 18–25, 25–30, and 30–50. This approach allows for meaningful comparisons and prevents results from being skewed.

3. Results

3.1. Statistical Analysis

This section presents the results from the 3-way ANOVA test, followed by the results from the non-parametric Friedman test and the post hoc pairwise comparison. For each test, the reported p-values represent the probability that the observed data would occur by chance, with values below 0.05 indicating statistical significance. For instance, in the ANOVA analysis, significant p-values (<0.05) associated with "Blinds", "CCT", and "Sky" suggest these factors significantly influence the perceptions of the environment. The p-values denoted by p[HF] indicate the application of the Huynh–Feldt correction for the ANOVA test, used when there is a violation of the sphericity assumption. This correction ensures a more accurate assessment of statistical significance. The F value, derived from the ANOVA results, measures the ratio of variation between the group means compared to the variation within the groups. A higher F value suggests a more substantial difference in how the variables affect perceptions, indicating a significant impact of the tested factors on participants' impressions.

The results of the 3-way ANOVA conducted for the three independent variables, "Sky", "Blinds", and "CCT", show varying degrees of influence of the different levels of these factors on participants' perceptions of light.

Statistical analysis revealed that both "Blinds" and "CCT" significantly influenced participants' perceptions. Specifically, "CCT" affected perceptions of "Coziness" ($p = 6.00 \times 10^{-3}$, F = 5.699), "Tense" (p = 0.014, F = 4.69), "Calming" (p[HF] = 0.038, F = 4.095), "Likability" (p[HF] = 0.006, F = 7.191), and "Monotonous" (p[HF] = 0.041, F = 3.694). Similarly, "Blinds" had a significant impact on "Coziness" (p = 7.48 × 10^{-5}, F = 22.38), "Tense" (p = 0.004, F = 9.818), "Calming" (p = 0.028, F = 4.939), "Likability" (p = 0.066, F = 13.622), and "Monotonous" (p = 1.33 × 10^{-4}, F = 20.337) perceptions. These findings suggest that variations in the levels of these factors, such as different "CCT" levels or the presence of "Blinds", significantly impact how individuals perceive the environment in terms of the tested attributes.

However, for the impressions of "Lively" (p = 7.94 × 10^{-7} < 0.05, F = 42.476), "Impersonal" (p = 1.70 × 10^{-2} < 0.05, F = 6.495), "Exciting" (p = 2.89 × 10^{-5} < 0.05, F = 25.993), and "Vibrant"(p = 5.38 × 10^{-5} < 0.05, F = 23.602), only the influence of "Blinds" was significant. On the perception of "Productive", only "CCT" showed a main effect (p = 7.30 × 10^{-5}, F = 11.594). The effect of "Sky" on the tested lighting impressions was not significant (p > 0.05).

The investigation into the interaction effects between the independent variables revealed significant impacts across various perceptions. Interaction analysis assesses how the effect of one independent variable on the dependent variable is influenced by the levels of another independent variable. The interaction effect between "CCT" and "Blinds" revealed a significant effect (p < 0.05) across all perceptions except for "Calming" (p = 0.07, F = 2.81). For the perception of "Cozy" (p = 0.016, F = 4.701) and "Lively" (p[HF] = 2.04 × 10^{-9} < 0.05, F = 30.663), the interaction effect demonstrated statistical significance, indicating a substantial impact of the combined influence of "CCT" and "Blinds" on individuals' feelings of "Coziness". Additionally, in perceptions such as "Tense" (p[HF] = 0.001 < 0.05, F = 7.896), "Impersonal" (p[HF] = 1.67 × 10^{-5} < 0.05, F = 14.718), "Exciting" (p[HF] = 0.007 < 0.05, F = 5.539), "Productive" (p[HF] = 7.82 × 10^{-5} < 0.05, F = 11.493), "Likability" (p[HF] = 0.011 < 0.05, F = 5.573), "Monotonous" (p[HF] = 0.001 < 0.05, F = 8.273), and "Vibrant" (p[HF] = 0.0003 < 0.05, F = 9.456), the interaction effect also exhibited significant influence. Similarly, there was statistically significant interaction between "Sky" and "Blinds" in creating perceptions such as "Lively" (p = 6.64 × 10^{-4}, F = 15.098), "Productive" (p = 4.00 × 10^{-3} < 0.05, F = 10.077), "Likability" (p = 0. 0.037, F = 4.876), and "Vibrant" (p = 0. 1.40 × 10^{-2} < 0.05, F = 7.013).

The interaction between "CCT", "Blinds", and "Sky" significantly influenced perceptions of "Cozy" (p = 1.40 × 10^{-2} < 0.05, F = 4.693), "Tense" (p = 0.043 < 0.05, F = 3.353), and "Productive" (p = 2.00 × 10^{-2} < 0.05, F = 4.609). Table A1 in Appendix A. includes full results from the ANOVA analysis, and Figure 4 shows a heatmap of the overall results of the ANOVA analysis.

Response	CCT	Blinds	SKY	CCT:Blinds	CCT:SKY	Blinds:SKY	CCT:Blinds:SKY
Cozy	P<0.01	P< 0.001		P<0.05			P<0.05
Lively		P< 0.001		P< 0.001		P< 0.001	
Tense	P<0.05	P< 0.005		P<0.01			P<0.05
Impersonal		P<0.05		P< 0.001			
Calming	P<0.05	P<0.05					
Exciting		P< 0.001		P<0.01			
Productive	P< 0.001			P< 0.001		P< 0.005	P<0.05
Likability	P<0.01	P<0.01		P<0.05	P<0.05	P<0.05	
Monotonous	P<0.05	P< 0.001		P< 0.001			
Vibrant		P< 0.001		P< 0.001		P<0.05	

P< 0.001
P< 0.005
P<0.01
P<0.05

Figure 4. ANOVA analysis, main effect and interactions.

The results from the Friedman test on paired independent variables highlight the interplay of different lighting variables on participants' subjective experiences. Lighting conditions grouped by the "Sky" and Blinds" variables showed significant differences in creating perceptions of "Lively" (x^2 = 29.8, p = 4.57744 × 10^{-6} < 0.05), "Tense" (x^2 = 13.12, p = 0.0131 < 0.05), "Exciting" (x^2 = 19.66. p = 0.0005 < 0.05), "Productive" (x^2 = 11.65, p = 0.0260< 0.05), "Monotonous" (x^2 = 21.511, p = 0.00025 < 0.05), and "Vibrant" (x^2 = 19.3855, p = 0.0007 < 0.05).

The lighting conditions grouped based on the pair "CCT-Blinds" exhibited significant differences in responses across all explored perceptions. The perception "Cozy"

(x^2 = 32.4, p = 1.48995 × 10^{-5} < 0.05), "Lively" (x^2 = 47.8, p = 1.16931 × 10^{-8} < 0.05), "Tense" (x^2 = 26.269, p = 0.00024 < 0.05), "Impersonal" (x^2 = 21.37, p = 0.0021< 0.05), "Calming" (x^2 = 18.0924, p = 0.0085 < 0.05), "Exciting" (x^2 = 27.706, p = 0.0001 < 0.05), "Productive" (x^2 = 34.2473, p = 6.37722 × 10^{-6} < 0.05), "Likability" (x^2 = 32.8678, p = 1.19935 × 10^{-5} < 0.05), "Monotonous" (x^2 = 29.6545, p = 5.17398 × 10^{-5} < 0.05), and "Vibrant" (x^2 = 33.9843, p = 7.19467 × 10^{-6} < 0.05) were significantly affected by variations in "CCT" and "Blinds" settings. For the "Sky-CCT" group, significant differences were observed only in the perceptions of "Cozy" (x^2 = 5.77, p = 0.0075 < 0.05), "Productive" (x^2 = 23.811, p = 0.0007 < 0.05), and "Likability" (x^2 = 20.502, p = 0.003 < 0.05). This suggests that while variations in "Sky" condition and "CCT" do influence certain perceptions, the effect is not as pronounced across all explored perceptions compared to the "CCT-Blinds" group (Table 3).

Table 3. Friedman test results on lighting conditions based on paired independent variables.

Perceptions	Paired Var.	Kendall's Coef. of Concordance (Corr. for Ties)	DF	Friedman Chi-Square Statistic (Corr. for Ties)	*p*-unc	*p*-Adjusted
Cozy (N = 26)	SKY-Blinds	0.2070	3	16.1434	0.001059722	0.003179165 *
	SKY-CCT	0.1214	5	15.7778	0.007508016	0.022524047.
	Blinds-CCT	0.2492	5	32.3928	4.9665 × 10^{-6}	1.48995 × 10^{-5} ***
Lively (N = 26)	SKY-Blinds	0.3820	3	29.7927	1.52581 × 10^{-6}	4.57744 × 10^{-6} ***
	SKY-CCT	0.0464	5	6.0327	0.303052752	0.909158255
	Blinds-CCT	0.3677	5	47.8023	3.89771 × 10^{-9}	1.16931 × 10^{-8} ***
Tense (N = 26)	SKY-Blinds	0.1682	3	13.1189	0.004386504	0.013159513.
	SKY-CCT	0.0598	5	7.7765	0.168992662	0.506977987
	Blinds-CCT	0.2021	5	26.2690	7.91297 × 10^{-5}	0.000237389 **
Impersonal (N = 26)	SKY-Blinds	0.1192	3	9.3000	0.025557028	0.076671084
	SKY-CCT	0.0212	5	2.7592	0.737047688	1
	Blinds-CCT	0.1644	5	21.3699	0.000689513	0.00206854 *
Calming (N = 26)	SKY-Blinds	0.0324	3	2.5301	0.469872223	1
	SKY-CCT	0.0856	5	11.1249	0.048959951	0.146879853
	Blinds-CCT	0.1392	5	18.0925	0.0028327	0.008498101 *
Exciting (N = 26)	SKY-Blinds	0.2521	3	19.6625	0.000199392	0.000598176 **
	SKY-CCT	0.0151	5	1.9632	0.854209596	1
	Blinds-CCT	0.2131	5	27.7059	4.15479 × 10^{-5}	0.000124644 **
Productive (N = 26)	SKY-Blinds	0.1494	3	11.6524	0.008674051	0.026022152.
	SKY-CCT	0.1832	5	23.8109	0.000236051	0.000708153 **
	Blinds-CCT	0.2634	5	34.2473	2.12574 × 10^{-6}	6.37722 × 10^{-6} ***
Likability (N = 26)	SKY-Blinds	0.1246	3	9.7171	0.021130182	0.063390547
	SKY-CCT	0.1577	5	20.5018	0.001005755	0.003017266 *
	Blinds-CCT	0.2528	5	32.8678	3.99785 × 10^{-6}	1.19935 × 10^{-5} ***
Monotonous (N = 26)	SKY-Blinds	0.2758	3	21.5106	8.24576 × 10^{-5}	0.000247373 **
	SKY-CCT	0.1017	5	13.2213	0.021390712	0.064172137
	Blinds-CCT	0.2281	5	29.6546	1.72466 × 10^{-5}	5.17398 × 10^{-5} ***
Vibrant (N = 26)	SKY-Blinds	0.2485	3	19.3855	0.000227533	0.000682598 **
	SKY-CCT	0.0584	5	7.5928	0.180150733	0.5404522
	Blinds-CCT	0.2614	5	33.9843	2.39822 × 10^{-6}	7.19467 × 10^{-6} ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'.

The results from the post hoc pairwise comparison (Table 4) showed no significant difference in the tested perceptions between the lighting conditions with sunny skies vs. overcast skies. For all responses except for "Productive", there was a significant difference observed between the conditions where "Blinds" were open vs. closed ($p < 0.05$). Perceptions of "Tense", "Calming", and "Likability" varied under different "CCT" values of "6500 K vs. 2700 K" ($p < 0.05$) and "4000 K and 2700 K" ($p < 0.05$). For the impression of "Cozy", the comparison showed differences between "CCT" levels of 4000 K and 6500 K ($p < 0.05$). The perception of "Productive" was significantly different between "4000 K vs. 6500 K" ($p < 0.0001$) and "4000 K vs. 2700 K" ($p < 0.0001$). No significant effect of "CCT" was observed for the responses "Lively", "Impersonal", "Exciting", and "Vibrant". The heatmaps in Figure 5 illustrate the results obtained from the Friedman and the post hoc pairwise comparison tests. In these heatmaps, the color-coding represents the significant differences between the levels of each independent variable and the significant interactions between pairs of independent variables for all responses.

Table 4. Pairwise comparison of levels of independent variables (post hoc Dunn test).

Responses N = 26		Independent Variables				
		Blinds	**Sky**	**CCT**		
		Yes/No	**Sunny vs. Overcast**	**2700 K vs. 4000 K**	**2700 K vs. 6500 K**	**4000 K vs. 6500 K**
Cozy	Z	4.508909	−0.776959	−1.472604	2.283394	3.755997
	p.unadj	0.000007	0.437183	0.140858	0.022407	0.000173
	p.adj	0.000007	0.437183	0.422574	0.067222	0.000518
Lively	Z	4.675515	0.632555	1.170720	−0.265573	−1.436293
	p.unadj	0.000003	0.527025	0.241711	0.790568	0.150919
	p.adj	0.000003	0.527025	0.725134	1.000000	0.452757
Tense	Z	−3.325510	0.000638	3.189866	3.073040	−0.116826
	p.unadj	0.000883	0.999491	0.001423	0.002119	0.906998
	p.adj	0.000883	0.999491	0.004270	0.006357	1.000000
Impersonal	Z	−3.920569	1.374141	1.62799119	1.586658	−0.041333
	p.unadj	0.000088	0.169398	0.103527	0.112590	0.967030
	p.adj	0.000088	0.169398	0.310580	0.337771	1.000000
Calming	Z	2.766437	−0.808582	−3.376829	−2.475767	0.901062
	p.unadj	0.005667	0.418756	0.000733	0.013295	0.367556
	p.adj	0.005667	0.418756	0.002200	0.039885	1.000000
Exciting	Z	4.488009	−0.538126	0.718234	−0.246856	−0.965091
	p.unadj	0.000007	0.590490	0.472613	0.805020	0.334500
	p.adj	0.000007	0.590490	1.000000	1.000000	1.000000
Productive	Z	1.798396	−0.729114	−0.976303	−5.173932	−4.197630
	p.unadj	0.072114	0.465932	0.329000	0.000000	0.000027
	p.adj	0.072114	0.465932	0.987000	0.000001	0.000081
Likability	Z	4.160223	−0.708840	−3.379549	−4.111441	−0.731892
	p.unadj	0.000032	0.478424	0.000726	0.000039	0.464000
	p.adj	0.000032	0.478424	0.002178	0.000118	1.000000
Monotonous	Z	−4.769300	1.863206	−1.842696	−2.935385	−1.092689
	p.unadj	0.000002	0.062433	0.065373	0.003331	0.274530
	p.adj	0.000002	0.062433	0.196120	0.009994	0.823591
Vibrant	Z	4.018118	−0.832265	1.285938	−0.873022	−2.158960
	p.unadj	0.000059	0.405260	0.198465	0.382651	0.030853
	p.adj	0.000059	0.405260	0.595394	1.000000	0.092560

In summary, ANOVA analysis revealed that both “Blinds” and “CCT” influenced perceptions of “Cozy”, “Tense”, “Calming”, “Productive”, “Likability”, and “Monotonous”. Specifically, “Blinds” were shown to significantly influence participants’ perceptions of “Lively”, “Impersonal”, “Exciting”, and “Vibrant”. Additionally, there was an interaction between “CCT” and “Blinds” across all tested perceptions, except for “Calming”. While “Sky” alone did not significantly influence indoor lighting perceptions, its interaction with “CCT” influenced the “Likability” of the space. Moreover, the interaction of “Blinds” and “Sky” influenced perceptions of “Lively”, “Productive”, “Likability”, and “Vibrant”.

Interactions between all three variables (“CCT”, “Sky”, and “Blinds”) were found to be statistically significant for perceptions of “Cozy”, “Tense”, and “Productive”, indicating that different combinations of these factors may influence perceptions differently compared to their individual effects.

Further analysis on the effect of lighting conditions based on paired independent variables showed a significant difference between at least two lighting conditions grouped based on “Blinds-CCT” for all tested variables. A similar effect was discovered for the pair “Sky-Blinds” for all perceptions except for “Impersonal”, “Calming”, and “Likability". Lighting conditions grouped based on "Sky-CCT" created significantly different impressions only on dimensions of "Cozy", "Productive", and "Likability".

Responses	Independent Variables				
	Blinds	Sky	CCT		
	Yes/No	Sunny vs Overcast	6500 vs 2700K	4000 K vs 2700K	4000 K vs 6500K
Cozy	P<0.001				P<0.001
Lively	P<0.001				
Tense	P<0.001		P<0.01	P<0.005	
Impersonal	P<0.001				
Calming	P<0.01		P<0.005	P<0.005	
Exciting	P<0.001				
Productive			P<0.001		P<0.001
Like/dislike	P<0.001		P<0.001	P<0.005	
Monotonous	P<0.001		P<0.01		
Vibrant	P<0.001				

Responses	Independent Variables		
	SKY and Blinds	Sky and CCT	Blinds and CCT
Cozy	P<0.01	P<0.05	P<0.001
Lively	P<0.001		P<0.001
Tense	P<0.05		P<0.001
Impersonal			P<0.01
Calming			P<0.01
Exciting	P<0.001		P<0.001
Productive	P<0.05	P<0.001	P<0.001
Like/dislike		P<0.01	P<0.001
Monotonous	P<0.001		P<0.001
Vibrant	P<0.001		P<0.001

P < 0.001
P < 0.005
P < 0.01
P < 0.05

Figure 5. **Left**: Pairwise comparison of levels of independent variables (post hoc Dunn test). **Right**: Friedman test results for lighting conditions based on paired independent variables.

Post hoc tests on the different levels of each independent variable showed significant differences between the conditions where "Blinds" were open vs. closed for all impressions except for "Productive". Similarly, pairwise comparisons of "CCT" levels showed varying influences of the tested levels on lighting impressions. No statistically significant difference was observed between sunny and overcast skies.

3.2. The Effect of Seat Location and Age on Light Perceptions

The results of the Kruskal–Wallis tests assessing the effects of age and seat location on light impression showed no statistically significant difference in the perception scores across the different age groups or seat zones and tested perceptions (Tables 5 and 6, respectively). The results indicate that there is no strong evidence suggesting that the lighting impressions vary significantly across the different seat zones or age groups.

Table 5. The effect of seat location on participant responses (Kruskal–Wallis test).

Perception	df	Kruskal–Wallis Chi-Squared	*p*-Value
Cozy (N = 26)	2	0.978484	0.613091
Lively (N = 26)	2	0.483128	0.785399
Tense (N = 26)	2	3.540454	0.170294
Impersonal (N = 26)	2	2.427811	0.297035
Calming (N = 26)	2	1.777576	0.411154
Exciting (N = 26)	2	1.358045	0.507112
Productive (N = 26)	2	1.191888	0.551042
Likability (N = 26)	2	2.917151	0.232567
Monotonous (N = 26)	2	0.097447	0.952444
Vibrant (N = 26)	2	1.558362	0.458782

Table 6. The effect of age on participant responses (Kruskal–Wallis test).

Perception	df	Kruskal–Wallis Chi-Squared	*p*-Value
Cozy (N = 26)	2	1.221912	0.542832
Lively (N = 26)	2	2.899571	0.234621
Tense (N = 26)	2	5.361260	0.068520
Impersonal (N = 26)	2	3.450821	0.178100
Calming (N = 26)	2	1.720018	0.423158
Exciting (N = 26)	2	1.213660	0.545076
Productive (N = 26)	2	0.833645	0.659138
Likability (N = 26)	2	0.302870	0.859474
Monotonous (N = 26)	2	2.645938	0.266343
Vibrant (N = 26)	2	0.002424	0.998789

3.3. Visualization

To visualize the patterns and differences between pairs of independent variables, three plots are generated per response (Figures 6 and 7). The graphs illustrate the interplay between pairs of "Sky-Blinds", "Sky-CCT", and "Blinds-CCT". In each graph, the distribution and centrality of data are visualized in the form of box plots and mean interaction (point) plots to show the magnitude and change of responses in relation to different variables and lighting conditions. The X-axis represents the levels of independent variables, while the Y-axis represents the response values. Both consistent patterns and mixed interactions are observed from the graphs across different responses and perceptions of space.

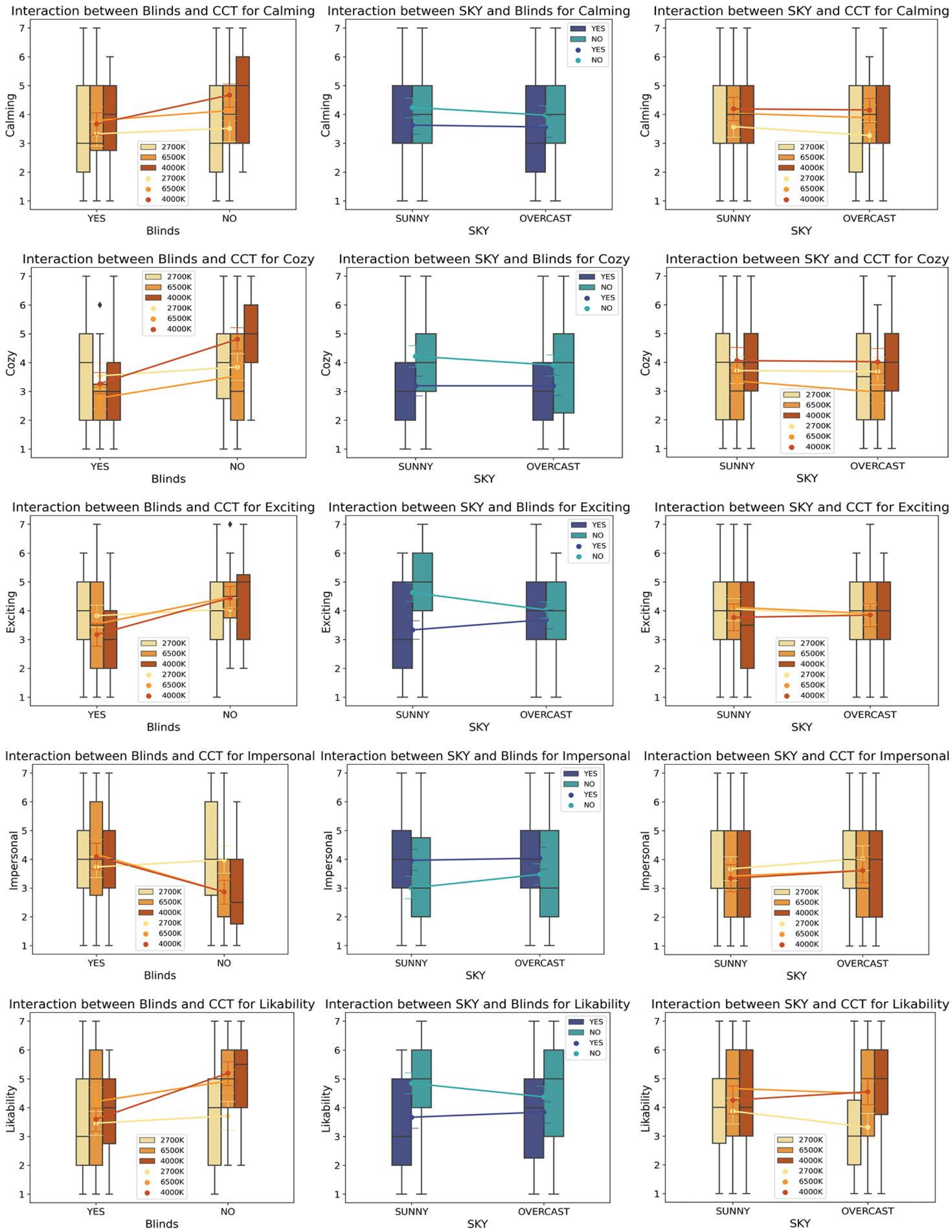

Figure 6. Impact of independent variables on perceptions: "Calming", "Cozy", "Exciting", "Impersonal", and "Likability". **Left**: "Blinds-CCT" groups. **Middle**: "Sky-Blinds" groups. **Right**: "Sky-CCT" groups.

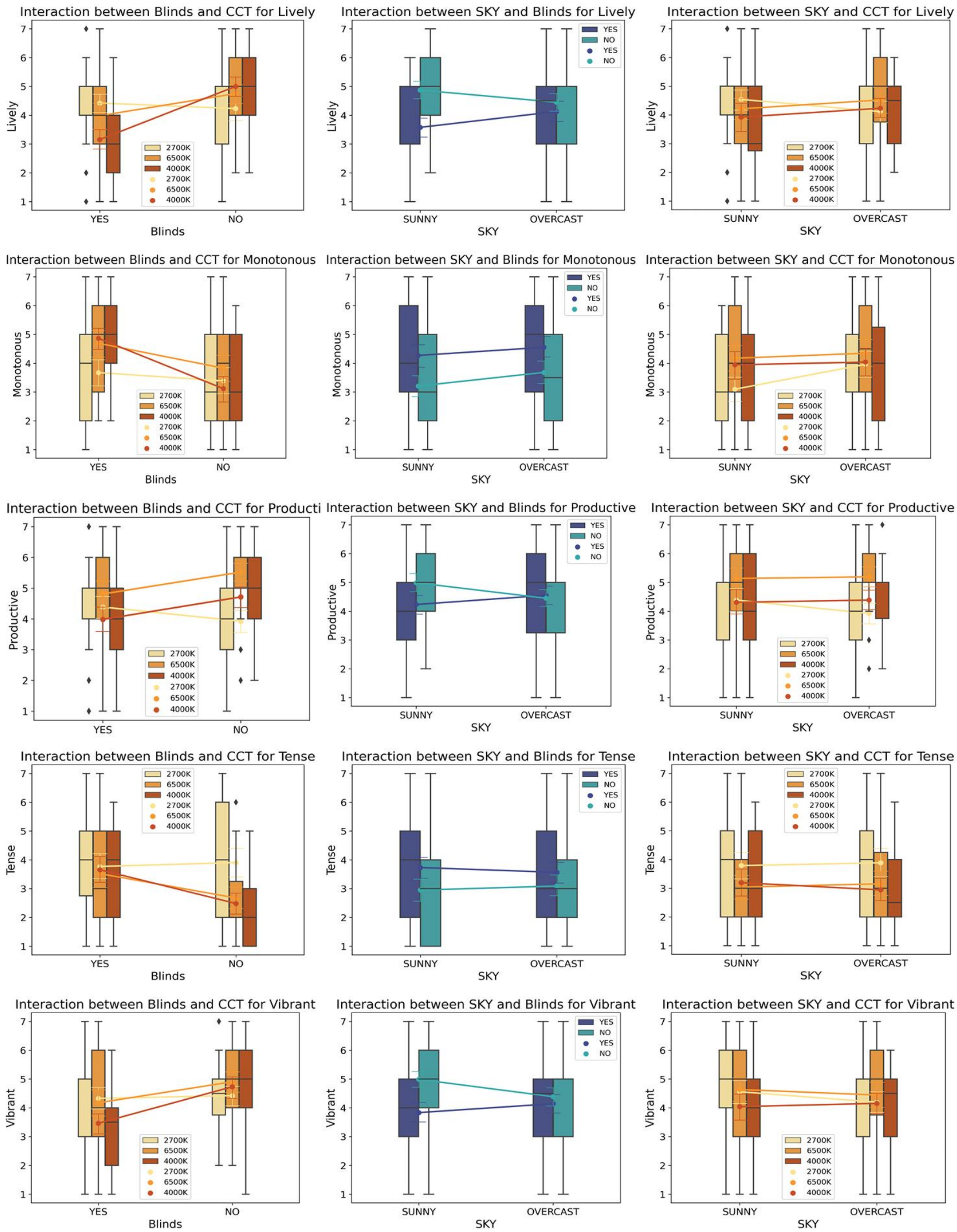

Figure 7. Impact of independent variables on perceptions: "Lively", "Monotonous", "Productive", "Tense", and "Vibrant". **Left**: "Blinds-CCT" groups. **Middle**: "Sky-Blinds" groups. **Right**: "Sky-CCT" groups.

Without "Blinds", responses were generally more positive for different "CCT" levels across impressions such as "Coziness", "Excitement", "Likability", "Productivity", "Vibrancy", and "Calming". Similarly, when the "Blinds" were open, the average votes for emotional responses like "Tenseness" and "Impersonality" decreased, and the lighting was perceived as more "Monotonous". Overall, under both "Blinds"' conditions, 4000 K lighting received higher ratings in relation to positive responses, while 2700 K "CCT" evoked fewer positive responses. Interactions were observed in some responses. For instance, across different impressions, although 4000 K was voted less positively on average with

"Blinds", the average vote improved in spaces without "Blinds". A similar pattern was observed for 6500 K. However, the pattern was reversed for 2700 K. While it was ranked more positively in cases where "Blinds" were present, it was ranked less positively when there were no "Blinds".

In the case of the "Sky" and "Blinds", the presence and absence of "Blinds" have varying effects on different impressions depending on the sky condition. Generally, lighting conditions were ranked more positively under both "Sky" conditions when the "Blinds" were open. In the absence of "Blinds", the average positive votes decreased under overcast skies. However, this pattern was reversed for closed "Blinds", as the mean positive votes for all responses either remained the same or improved under overcast skies compared to sunny skies. For impressions of "Productiveness" and "Monotonous", closed "Blinds" with overcast skies were ranked slightly more positively compared to the same "Sky" condition but with open "Blinds". There was limited interaction between "Sky" and "CCT" compared to "CCT" and "Blinds". The average positive rating for 2700 K decreased under overcast skies in most response categories such as "Lively", "Calming", "Productive", "Vibrant", and "Likability", while there was an increase in the average vote for impressions of "Tense", "Monotonous", and "Impersonal". In contrast, 4000 K and 6500 K showed consistency between different "Sky" conditions or were favored more under overcast "Sky" conditions compared to sunny skies in emotional responses such as "Lively" and "Productive".

4. Discussion

While the existing scientific literature provides valuable insights into various aspects of lighting and its impact on indoor environments, it is important to acknowledge the limited research specifically addressing the influence of both daylight and electric light. This study aimed to contribute to this underexplored area by comprehensively investigating the combined effects of these lighting sources on perceptions of indoor spaces.

The study demonstrates the complex interplay between daylight and electric light in shaping human perceptions of space in an office environment. The results reveal varying degrees of influence from each of the evaluated factors. "CCT" was shown to significantly influence participants' perceptions of space in categories such as "Cozy", "Tense", "Calming", "Monotonous", and "Likability", suggesting that manipulating "CCT" levels alone can create specific ambiences in space. The presence or absence of "Blinds" shows a strong influence in shaping participants' impressions of the space in relation to all emotional responses except for the perception of "Productive". Interestingly, the "Sky" condition alone did not significantly influence the perception of space. However, interactions between "Sky" conditions, "Blinds", and "CCT" indicate that under different "Sky" conditions, people may change their preferences for the position of "Blinds" or "CCT" levels.

The interaction between blind positions and "CCT", which was significant in all categories except for the impression of "Calming", highlights the importance of considering these variables in tandem, as the degree of the impact of each is dependent on the other. These findings also draw attention to indoor lighting compositions changing as a result of human behavior, such as blinds opening habits. Past research indicates that when people close blinds to mitigate visual discomfort due to glare, they forget to open them [34]. The findings from this study emphasize that indoor lighting design should consider compensation for potential changes in room ambiance under different sky conditions or the blinds' position due to human habits.

In some emotional responses, the presence of "Blinds" under overcast "Sky" conditions improved occupants' impression of space compared to the same lighting conditions with "Blinds" open or both "Blinds" open and closed. This finding, at first sight, might be in contrast with the general usage of blinds, as they are not as commonly used during overcast sky conditions. However, it also highlights that blinds might play a crucial role even under overcast sky conditions. It is important to note that increased positive responses for "Blinds" on overcast days might be due to factors such as the light color of the blinds, their texture, or similar characteristics. The impact of blinds with darker shades/colors or textures on enhancing user perception and satisfaction might not be as pronounced. Future research could further explore these aspects by incorporating different colors and textures of blinds.

The findings carry practical implications for the fields of architecture and lighting design, emphasizing the need for adaptable and flexible lighting solutions. Architects typically design buildings with careful consideration of environmental factors and maximizing the benefits of daylight. However, the findings from this research emphasize the importance for architects to also account for how the space will function with electric lighting when planning buildings and facades. Additionally, the study revealed the significant impact that different lighting compositions can have on the perception of an everyday office space. This underscores the necessity of considering environmental factors, users' tasks, and the desired mood or preferences when designing electric lighting. This research may have particular application in the design and operation of smart building systems, where sensing and intelligent technologies are integrated to actuate electric lights and blinds based on real-time environmental data, creating optimal indoor lighting conditions. Current smart building systems in offices prioritize task and visual comfort by responding to environmental factors such as daylight quantity to adjust blinds and electric light conditions. However, they may fall short in providing a diverse range of lighting scenes needed in dynamic environments like office settings, where the requirements for creative work, focused tasks, and collaborative efforts vary significantly. The study highlights the importance of developing smart lighting systems capable of accommodating these varied needs to enhance occupant satisfaction and comfort in office spaces. Controlling dynamic lighting in shared office spaces is challenging due to diverse user preferences and needs.

The findings shed light on the challenges of lighting control in office settings, where users often have limited autonomy over adjusting lighting settings. Thus, it is imperative to provide users with the flexibility to customize lighting according to their preferences and specific activities within the space. As demonstrated by this study, this adaptability may extend beyond providing sufficient light for task performance and encompass various aspects, such as offering options for selecting specific light CCTs to create the desired atmosphere or mood. The findings may initially be applicable to private offices, where both ambient and task lighting can be adjusted automatically or manually according to individual preferences. These applications can be extended to shared environments by adopting established methods of shared office lighting control, such as implementing proper zoning of ambient lights [41], providing separate and individually controlled ambient and task lighting [5,42], and allowing dynamic adjustment of ambient lights based on environmental factors and collective votes within each zone [41,43].

5. Conclusions

This study explored the combined effects of daylight and electric light on human perception of indoor lighting across various impressions in an office space. The results demonstrate the complex interplay between the attributes of daylight and electric light, particularly the roles of blinds and CCT, in shaping indoor lighting conditions and, consequently, human perception. The interaction between these factors highlights the complexity of optimizing indoor environments to meet individual needs and preferences.

The findings from this experiment emphasize the importance of creating personalized lighting solutions that can adjust to changing external conditions and occupant preferences, thereby enhancing the health, comfort, and sustainability of indoor environments. Further research is warranted to explore additional factors influencing lighting perceptions and to validate the effectiveness of personalized lighting solutions in diverse real-world settings.

Limitations

The participants evaluated the lighting conditions during brief periods of exposure and the measurement of perceptions relied on subjective ratings. Future work will address these limitations by extending the exposure time to each lighting condition and by incorporating objective measures, such as physiological responses or task performance outcomes under each lighting condition. Dynamically changing and controlling indoor lighting in shared spaces to accommodate individual preferences can be challenging. Therefore, the next phases of this research will assess the application of this paper's findings in implementing and controlling a user-centric automated dynamic lighting system in both private and shared offices. The experiment was conducted in a small office space, which might not fully represent the diversity of real-world settings. In addition, spatial and architectural factors such as room shape, layout, wall, and furniture color may have influenced participant responses during the experiment. Future work could explore the impact of these factors in various types of spaces, such as open offices, homes, and healthcare facilities.

The study used a specific group of young participants in a specific setting of a small office, which may limit the generalizability of the findings to other populations or environments. Future work will strive for larger sample sizes and environments to enhance the generalizability of the findings.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Three-way ANOVA test results for "Sky", "Blinds", and "CCT" across various perceptions.

Response	Effect	DFn	DFd	F	*p*	ges	W	*p*	HFe	DF [HF]	*p* [HF]
Cozy (N = 26)	CCT	2	50	5.699	6.00×10^{-3} *	0.053	0.857	0.158	0.936	1.87, 46.79	0.007 *
	Blinds	1	25	22.381	7.48×10^{-5} *	0.074					
	SKY	1	25	0.866	3.61×10^{-1}	0.002					
	CCT:Blinds	2	50	4.701	1.30×10^{-2} *	0.026	0.829	0.105	0.91	1.82, 45.5	0.016 *
	CCT:SKY	2	50	0.631	5.36×10^{-1}	0.003	0.91	0.323	0.987	1.97, 49.33	0.534
	Blinds:SKY	1	25	0.805	3.78×10^{-1}	0.002					
	CCT:Blinds:SKY	2	50	4.693	1.40×10^{-2} *	0.017	0.805	0.074	0.89	1.78, 44.48	0.017 *
Lively (N = 26)	CCT	2	50	0.819	4.47×10^{-1}	0.009	0.425	3.45×10^{-5} *	0.653	1.31, 32.67	4.03×10^{-1}
	Blinds	1	25	42.476	7.94×10^{-7} *	0.084					
	SKY	1	25	0.125	7.27×10^{-1}	0.000579					
	CCT:Blinds	2	50	30.663	2.04×10^{-9} *	0.089	0.942	4.90×10^{-1}	1.021	2.04, 51.03	2.04×10^{-9} *
	CCT:SKY	2	50	2.884	6.50×10^{-2}	0.016	0.976	7.43×10^{-1}	1.058	2.12, 52.89	6.50×10^{-2}
	Blinds:SKY	1	25	15.098	6.64×10^{-4} *	0.032					
	CCT:Blinds:SKY	2	50	2.797	7.10×10^{-2}	0.01	0.929	4.13×10^{-1}	1.006	2.01, 50.31	7.10×10^{-2}
Tense (N = 26)	CCT	2	50	4.69	0.014 *	4.80×10^{-2}	0.5	0.000247 *	0.69	1.38, 34.52	0.027 *
	Blinds	1	25	9.818	0.004 *	3.80×10^{-2}					
	SKY	1	25	0.006	0.941	1.64×10^{-5}					
	CCT:Blinds	2	50	7.896	0.001 *	3.00×10^{-2}	0.888	0.239	0.964	1.93, 48.21	0.001 *
	CCT:SKY	2	50	0.956	0.391	3.00×10^{-3}	0.939	0.469	1.017	2.03, 50.84	0.391
	Blinds:SKY	1	25	1.924	0.178	2.00×10^{-3}					
	CCT:Blinds:SKY	2	50	3.353	0.043 *	1.10×10^{-2}	0.942	0.488	1.02	2.04, 51.01	0.043 *
Impersonal (N = 26)	CCT	2	50	1.307	2.80×10^{-1}	0.011	0.583	0.002 *	0.736	1.47, 36.78	2.75×10^{-1}
	Blinds	1	25	6.495	1.70×10^{-2} *	0.052					
	SKY	1	25	2.607	1.19×10^{-1}	0.007					
	CCT:Blinds	2	50	14.718	9.41×10^{-6} *	0.046	0.855	0.153	0.934	1.87, 46.69	1.67×10^{-5} *
	CCT:SKY	2	50	0.074	9.29×10^{-1}	0.00047	0.955	0.574	1.034	2.07, 51.71	9.29×10^{-1}
	Blinds:SKY	1	25	2.081	1.62×10^{-1}	0.004					
	CCT:Blinds:SKY	2	50	1.557	2.21×10^{-1}	0.004	0.94	0.476	1.018	2.04, 50.9	2.21×10^{-1}
Calming (N = 26)	CCT	2	50	4.095	0.023 *	0.041	0.526	0.000446 *	0.704	1.41, 35.18	0.038 *
	Blinds	1	25	4.939	0.036 *	0.028					
	SKY	1	25	1.14	0.296	0.003					
	CCT:Blinds	2	50	2.81	0.07	0.013	0.994	0.933	1.08	2.16, 54	0.07
	CCT:SKY	2	50	0.386	0.682	0.001	0.933	0.434	1.01	2.02, 50.51	0.682
	Blinds:SKY	1	25	0.528	0.474	0.001					
	CCT:Blinds:SKY	2	50	0.26	0.772	0.001	0.751	0.709	0.788	1.58, 39.42	0.72

Table A1. *Cont.*

Response	Effect	DFn	DFd	F	*p*	ges	W	*p*	HFe	DF [HF]	*p* [HF]
Exciting (N = 26)	CCT	2	50	0.392	6.78×10^{-1}	0.004	0.588	0.002 *	0.738	1.48, 36.9	0.616
	Blinds	1	25	25.993	2.89×10^{-5} *	0.077					
	SKY	1	25	0.408	5.29×10^{-1}	0.002					
	CCT:Blinds	2	50	5.539	7.00×10^{-3} *	0.023	0.957	0.592 *	1.037	2.07, 51.84	0.007 *
	CCT:SKY	2	50	0.451	6.40×10^{-1}	0.002	0.98	0.783	1.063	2.13, 53.14	0.64
	Blinds:SKY	1	25	14.209	8.93×10^{-4} *	0.028					
	CCT:Blinds:SKY	2	50	1.613	2.10×10^{-1}	0.007	0.892	0.254	0.969	1.94, 48.43	0.21
Productive (N = 26)	CCT	2	50	11.594	7.30×10^{-5} *	0.101	0.638	0.005 *	0.769	1.54, 38.44	3.52×10^{-4} *
	Blinds	1	25	4.218	5.10×10^{-2}	0.015					
	SKY	1	25	0.558	4.62×10^{-1}	0.002					
	CCT:Blinds	2	50	11.493	7.82×10^{-5} *	0.044	0.952	0.553	1.031	2.06, 51.55	7.82×10^{-5} *
	CCT:SKY	2	50	1.419	2.51×10^{-1}	0.009	0.773	0.045	0.864	1.73, 43.19	2.52×10^{-1}
	Blinds:SKY	1	25	10.077	4.00×10^{-3} *	0.026					
	CCT:Blinds:SKY	2	50	4.609	1.50×10^{-2} *	0.015	0.748	0.031	0.845	1.69, 42.23	2.00×10^{-2}*
Likability (N = 26)	CCT	2	50	7.191	0.002 *	0.067	0.505	0.000273	0.693	1.39, 34.63	0.006 *
	Blinds	1	25	13.622	0.001 *	0.066					
	SKY	1	25	1.032	0.319	0.002					
	CCT:Blinds	2	50	5.573	0.007 *	0.03	0.712	0.017	0.818	1.64, 40.92	0.011 *
	CCT:SKY	2	50	3.753	0.03 *	0.012	0.889	0.242	0.965	1.93, 48.26	0.032 *
	Blinds:SKY	1	25	4.876	0.037 *	0.01					
	CCT:Blinds:SKY	2	50	1.207	0.308 *	0.005	0.997	0.96	1.083	2.17, 54.14	0.308
Monotonous (N = 26)	CCT	2	50	3.694	0.032 *	0.033	0.722	0.02	0.826	1.65, 41.29	0.041 *
	Blinds	1	25	20.337	0.000133 *	0.081					
	SKY	1	25	3.799	0.063	0.013					
	CCT:Blinds	2	50	8.273	0.000787 *	0.033	0.814	0.085	0.898	1.8, 44.89	0.001 *
	CCT:SKY	2	50	2.612	0.083	0.011	0.932	0.428	1.009	2.02, 50.46	0.083
	Blinds:SKY	1	25	0.366	0.55	0.000868					
	CCT:Blinds:SKY	2	50	0.655	0.524	0.002	0.966	0.659	1.047	2.09, 52.33	0.524
Vibrant (N = 26)	CCT	2	50	2.181	1.24×10^{-1}	0.017	0.623	0.003	0.759	1.52, 37.97	0.138
	Blinds	1	25	23.602	5.38×10^{-5} *	0.061					
	SKY	1	25	0.638	4.32×10^{-1}	0.003					
	CCT:Blinds	2	50	9.456	3.29×10^{-4} *	0.03	0.942	0.491	1.021	2.04, 51.03	0.0003 *
	CCT:SKY	2	50	0.815	4.48×10^{-1}	0.005	0.974	0.733	1.057	2.11, 52.83	0.448
	Blinds:SKY	1	25	7.013	1.40×10^{-2} *	0.027					
	CCT:Blinds:SKY	2	50	3.165	5.10×10^{-2}	0.012	0.993	0.921	1.079	2.16, 53.93	0.051

Signif. code: 0.05 '*'.

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