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Article

Investigating the biomechanical impact of lighting placement on visual and physical comfort in living room interior design

Yabin Chen*, **Qiong Wu, Shijia Wang**

City University of Wuhan, Wuhan 430083, China
*** Corresponding author:** Yabin Chen, chenyb0423@outlook.com

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Abstract: Lighting is a key factor in shaping comfort, ambiance, and functionality within residential spaces, influencing not only visibility but also a room's overall experience and usability. In living rooms, where activities range from socializing and relaxation to reading and television viewing, lighting design must balance visual clarity, warmth, and adaptability to meet diverse needs. This study investigates the effects of specific lighting placements—overhead, wall-mounted, and floor/table lamp setups—across warm (2700 K), neutral (4000 K), and cool (6500 K) color temperatures on visual and physical comfort in a simulated residential living room environment. Using a mixed-methods approach, quantitative metrics, such as brightness consistency and luminance contrast, were combined with qualitative assessments of perceived comfort and activity suitability. Findings reveal that warm-toned floor and table lamps (2700 K) provide the highest levels of perceived warmth and relaxation, with average ratings of 4.9 and 4.8, making them particularly suitable for social and leisure activities. Overhead lighting in cool tones (6500 K) enhanced visual clarity, achieving an average clarity rating of 4.5, making it more suited to tasks requiring focused attention, such as reading. Wall-mounted lighting in neutral tones (4000 K) offered a balanced solution, with comfort and activity suitability ratings of 4.5, supporting a range of activities without compromising ambiance or clarity. These results underscore the importance of selecting lighting configurations that align with the intended use of residential spaces. Warm lighting, especially at lower levels, creates a cozy, inviting atmosphere most effectively, while cooler overhead lighting offers enhanced brightness and clarity for more visually demanding tasks. By highlighting the impact of lighting placement and color temperature on residential comfort, this study provides practical insights for interior designers and homeowners, contributing to developing adaptable, user-centered lighting solutions that optimize functionality and ambiance in home environments.

Keywords: biomechanical; residential lighting; visual comfort; color temperature; lighting placement; ambiance

1. Introduction

Lighting Design (LD) has emerged as a pivotal factor in creating comfortable, functional, and aesthetically pleasing residential environments [1]. Beyond providing visibility, lighting influences occupants' psychological and physiological well-being, shaping the overall ambiance, mood, and spatial perception within a home [2,3]. This shift reflects a growing understanding of the complex ways that lighting affects comfort, contributing to the importance of LD as a key element in interior architecture [4–6]. Properly designed lighting enhances a home's appeal, offering utility and an inviting atmosphere supporting various activities [7].

Lighting supports diverse activities in residential spaces, particularly in multi-functional areas like the living room [8]. The living room typically serves as a flexible environment for relaxation, socializing, reading, and screen-based activities, each benefiting from specific lighting qualities. Warmer lighting is often associated with a relaxing ambiance suited to social settings, while cooler lighting is better suited to tasks requiring visual clarity [9,10]. These lighting characteristics underscore the importance of adaptable solutions that support comfort, functionality, and well-being [11]. The recent advancements in tunable and customizable lighting systems reflect this trend, enabling residential lighting to accommodate diverse user needs by adjusting light intensity and color temperature for specific activities [12,13].

However, while much research has been conducted on lighting in commercial and workplace settings, comparatively few studies focus on residential lighting's impact on comfort and ambiance. The generalization of workplace lighting principles to residential settings fails to address the unique demands of home environments, where comfort and personalization are prioritized over functionality alone.

Furthermore, existing literature lacks an in-depth understanding of how specific lighting placements, such as overhead, wall-mounted, and floor-level configurations, affect comfort in the context of a residential living room. To address these gaps, this study investigates the effects of various lighting placements and color temperatures on visual and physical comfort within a residential living room setting. By combining quantitative measurements such as brightness consistency and luminance contrast with qualitative assessments of perceived comfort and ambiance, the study aims to identify lighting configurations that best support comfort and activity suitability in home environments.

The remainder of this paper is organized as follows. Section 2 reviews relevant literature on the role of residential lighting in influencing comfort and ambiance. Section 3 details the study's methodology, including the experimental setup, participant recruitment, and data collection processes. Section 4 presents the results, focusing on comfort and ambiance across different lighting configurations. Finally, Section 5 concludes the paper with key insights and suggestions for future research on residential LD.

2. Literature review

Recent studies emphasize the role of lighting in enhancing comfort and ambiance within residential spaces, with a particular focus on user-centric approaches that cater to individual preferences in lighting settings. For example, [14] highlights that residential lighting is crucial for creating a visually comfortable environment, where lighting can affect visual clarity and emotional responses within a space. Smart and tunable lighting systems have gained popularity for their ability to adjust to different lighting needs based on time, mood, and activities, particularly relevant for spaces like living rooms where varied activities occur [15]. While substantial research has been conducted in commercial lighting, studies focused explicitly on lighting in living rooms remain limited. Existing literature tends to generalize lighting effects across different room types, often applying workplace or commercial findings to residential spaces without tailored insights for homes, where comfort is often prioritized over functionality.

Light intensity, color temperature, and placement are key visual and physical comfort determinants in living environments. Intensity and color temperature significantly influence mood and comfort, with recent studies showing that warmer lighting (around 2700 to 3000 K) can create a relaxing atmosphere suitable for evening use in living rooms [16]. Meanwhile, lighting intensity must balance sufficient brightness for visibility without causing glare, as high-intensity lighting has been shown to increase visual discomfort [17]. Placement is another critical factor influencing light distribution and shadow formation. Recent findings suggest that lower, dispersed lighting sources—such as floor and table lamps—can reduce harsh shadows and distribute light more evenly, enhancing physical and visual comfort [18]. Additionally, [19] highlights the psychological impact of lighting in homes, noting that optimal lighting placement can improve perceptions of warmth and spaciousness, key comfort components in living rooms.

Despite these advances, significant gaps remain in understanding the specific impacts of lighting placement on comfort within living rooms. While recent studies explore the role of tunable and human-centric lighting in commercial and healthcare environments, their application in residential living rooms is less explored [20]. Current literature also lacks extensive insights into how various placements—such as overhead, wall-mounted, and floor-level lighting—affect comfort in living rooms, where ambient and task lighting needs vary by activity. Thus, future research should fill these gaps by examining user preferences for lighting placements and assessing their effects on visual and physical comfort in residential contexts.

3. Methodology

3.1. Study design

This study employs a mixed-methods design to analyze the impact of lighting placement on visual and physical comfort within a residential living room setting. The research approach combines quantitative measurements of light intensity, color temperature, and distribution with qualitative assessments of participant comfort levels to provide a holistic understanding of lighting's effect on living space environments [21–24].

Figure 1. Living room setup.

A standardized living room setup (**Figure 1**) was created to simulate typical residential lighting conditions, incorporating various lighting sources commonly found in homes, including ceiling-mounted lights, wall-mounted fixtures, and floor and table lamps. Each lighting source was strategically placed to examine various lighting configurations and their impact on the room's ambiance and participant perceptions of comfort. The study includes three primary lighting setups: overhead-focused, wall-mounted, and a combination setup using both overhead and supplementary ambient lighting. Each configuration is tested across three different color temperature settings (2700 K, 4000 K, 6500 K) to explore the influence of lighting warmth on comfort perception, particularly during different times of the day.

The study's design allows for both controlled lighting changes and adaptability, as participants experience each lighting setup during activities typical of living room use, such as reading, watching TV, and socializing. This variety is intended to reflect the multi-functional nature of residential spaces and to gauge lighting needs across various activities. Objective measurements, including light levels in lux and spectral data, are taken at the participant's eye level for each setup to capture the lighting conditions' impact on visual clarity and comfort. Simultaneously, participants complete standardized comfort assessment surveys to provide subjective feedback on each lighting arrangement, focusing on brightness, glare, shadow distribution, and general comfort.

Data is collected over multiple sessions to account for daily variation in natural light and to evaluate participants' adaptability to different lighting placements. Combining objective measures with subjective comfort assessments, this design comprehensively evaluates how different lighting placements contribute to perceived comfort in residential living room settings.

3.2. Participants

This study involved 27 participants, all residing in urban areas of China, selected to represent a range of demographic characteristics typical of residential living room users. Participants were recruited through online advertisements and community postings in local neighborhoods to ensure a diverse sample. The demographic profile included individuals aged 25 to 55, with an equal gender representation. The age range was chosen to capture a variety of perspectives on lighting comfort, as visual comfort preferences and needs may vary with age.

Participants were selected based on different residential layouts and lighting habits to enhance further demographic diversity, such as preferences for natural light usage versus artificial lighting. All participants reported spending substantial time in their living rooms during the evening, making them suitable for evaluating comfort in lighting placements for home environments. Recruitment prioritized individuals with typical lifestyle patterns to best simulate real-life living room usage and comfort responses under varied lighting configurations. Before the study, each participant provided informed consent and completed a brief survey on their general lighting preferences, which helped tailor the study setups to meet the comfort expectations of a general residential audience.

3.3. Apparatus

The study employed various lighting equipment and measurement tools to analyze the effects of different lighting placements on visual and physical comfort in a residential living room setting. The primary lighting apparatus included adjustable LED light sources with varying fixtures: ceiling-mounted, wall-mounted, and floor lamps. Each fixture type was selected to simulate standard residential lighting configurations, allowing for adjustable intensity and color temperature to test settings at 2700 K (Warm), 4000 K (Neutral), and 6500 K (Cool). These adjustable LED sources provided flexibility to create distinct lighting setups that could be modified to represent typical usage scenarios in residential environments [25–28].

A lux meter and spectrometer were used to measure light levels and color distribution accurately. The lux meter measured light intensity at different locations and participant eye levels within the room, capturing variations in brightness that may influence comfort. The spectrometer provided spectral data for each lighting configuration, allowing an analysis of color temperature and distribution to determine how these factors impact visual comfort. Both devices were calibrated before each session to ensure consistent and reliable data collection.

Additional equipment included a digital camera for documenting lighting conditions and spatial arrangements and a survey tablet used by participants to complete comfort assessments in real-time during each lighting setup. The living room was furnished with typical home furniture, including a sofa, coffee table, and bookshelves, to provide a realistic environment for participants to engage in different activities. Blackout curtains were installed to minimize natural interference and maintain controlled lighting conditions throughout the sessions. This apparatus setup enabled precise control and measurement of lighting effects, facilitating a thorough assessment of how each configuration influences comfort in a residential context.

3.4. Variables and measurements

The study examined several key variables to assess the impact of lighting placement on visual and physical comfort in a residential living room setting. The independent variables included lighting placement, light intensity, and color temperature. To analyze how these arrangements influence comfort and ambiance, lighting placement was manipulated by testing different configurations, including ceiling-mounted, wall-mounted, and floor/table lamp combinations. Light intensity levels were adjustable across low, medium, and high settings, measured in lux, to determine the role of brightness in visual clarity and comfort. Color temperature was tested at three levels—warm (2700 K), neutral (4000 K), and cool (6500 K)—to explore how different temperatures impact mood, relaxation, and comfort within the space [29,30].

The dependent variables focused on visual comfort, physical comfort, and perceived ambiance. Visual comfort was assessed by gathering participant feedback on brightness, glare, and shadow distribution, where each lighting setup was rated using a standardized visual comfort scale. Participants responded to ease of viewing, visual fatigue, and glare disturbances, offering insights into the effects of lighting configurations on visual clarity. Physical comfort was evaluated based on participants' sense of warmth and spatial comfort, with ratings indicating how cozy, relaxing, or spacious each lighting arrangement felt. Measurements were taken at multiple points in the room to capture how different lighting placements influenced spatial perception and physical comfort [31–32].

Perceived ambiance was another critical measurement, as participants rated each configuration for aspects like coziness, relaxation, and suitability for everyday living room activities such as reading, watching television, and socializing. Surveys after each setup used Likert scales to quantify visual and physical comfort levels, supplemented with open-ended questions to gather qualitative insights into the ambiance created by each lighting arrangement. To support these measurements, a lux meter was employed to record light intensity at different points and heights within the room, and a spectrometer was used to capture precise color temperature and spectral data for each lighting setup. Comfort surveys were completed by participants after each configuration, allowing for a combination of quantitative and qualitative data collection that provided a comprehensive understanding of how lighting placement impacts comfort and satisfaction in a living room setting. The following **Table 1** presents the measurements and variables in this study.

Table 1. Measurements and variables.

Variable type	Variable	Description	Measurement tools
Independent	Lighting placement	Placement of lights (Overhead, Wall-Mounted, the combination of floor and table lamps)	N/A (Setup variations)
Independent	Light intensity	Light intensity levels (Low, Medium, high) measured in lux	Lux Meter
Independent	Color temperature	Color temperature settings (2700 K-Warm, 4000 K-Neutral, 6500 K- Cool)	Spectrometer
Dependent	Visual comfort	Assessed through ratings on brightness, glare, and shadow distribution	Standardized visual comfort scale
Dependent	Physical comfort	Evaluated through ratings of spatial warmth, relaxation, and comfort	Comfort rating scale
Dependent	Perceived ambiance	Participants' perceptions of coziness, relaxation, and suitability for activities	Ambiance rating survey

3.5. Experimental design

The experiment was conducted in a controlled residential living room environment to assess how various lighting placements affect visual and physical comfort. Participants entered the simulated living room space, designed with common home furniture, including a sofa, coffee table, and bookshelves, to create a realistic setting. Blackout curtains were used to eliminate interference from external light sources and ensure the lighting setups could be accurately isolated and evaluated. Upon entering, each participant received instructions on the study's purpose and a detailed overview of the experiment's structure. They were informed that they would experience different lighting configurations, including overhead lighting, wall-mounted lighting, and a combination of floor and table lamps, across three color temperature settings: 2700 K (Warm), 4000 K (Neutral), and 6500 K (Cool). Participants were guided to approach each lighting setup as they would in a typical living room setting, performing activities that reflect standard living room use, such as reading, watching television, and engaging in conversation. They were instructed to pay attention to their visual comfort (e.g., clarity of sight, glare, brightness), physical comfort (e.g., warmth, spatial perception), and the ambiance each lighting configuration created.

Each participant experienced each lighting configuration for a set period of 10 min–15 min. This duration allowed them to adapt to each lighting condition and form accurate perceptions of comfort. During each session, participants were asked to perform specified activities:

- Reading: They read a short passage, allowing assessment of visual comfort related to brightness, glare, and shadow distribution.
- Watching Television: This activity enabled the evaluation of overall ambient lighting and how each configuration affected relaxation and spatial comfort.
- Socializing (Simulated): Participants were encouraged to sit as if conversing with someone, focusing on comfort and spatial perception under each lighting setup.

Objective measurements were taken using a lux meter and spectrometer to standardize data collection and document light intensity and color temperature at different eye levels and around key activity zones. These measurements ensured consistency across sessions and provided quantitative data on the lighting environment.

After each lighting setup, participants completed a comfort assessment survey on a tablet, which collected subjective ratings on visual and physical comfort and perceived ambiance. The survey used a Likert scale to rate brightness, glare, shadow distribution, spatial warmth, and relaxation. Participants were also asked open-ended questions to provide qualitative feedback on discomfort or preferences for specific lighting setups.

Participants were given a 5-minute rest period between sessions to mitigate potential carryover effects between lighting configurations. During this time, they could relax outside the test area, ensuring that any lingering effects from one lighting condition did not impact their perception of the next. Combining objective measurements with subjective feedback and controlled participant activities, this experimental structure allowed for a comprehensive analysis of how different lighting placements impact comfort in residential living rooms.

3.6. Metrics of assessment

This study utilized objective measurements and subjective ratings to assess the impact of lighting configurations on visual and physical comfort. Specific metrics, equations, and measurement techniques were employed to quantitatively evaluate each setup and provide a structured analysis of how lighting placement influences comfort.

1) Illuminance (E): Illuminance is a fundamental measure of brightness, describing the amount of light falling on a surface. It was measured in lux at different points in the room, including participant eye level and activity zones, to evaluate brightness consistency across each lighting configuration. This is critical for determining whether lighting intensity provides adequate illumination without causing glare or discomfort.

$$E = \frac{\Phi}{A} \tag{1}$$

where:

- E represents illuminance (in lux),
- Φ is the luminous flux incident on a surface (in lumens),
- A is the area (in square meters) over which the luminous flux is distributed.

By measuring illuminance, we ensured that each lighting configuration offered sufficient light levels for comfort during various activities, such as reading and watching television.

2) Luminance Contrast (C): Luminance contrast quantifies the brightness difference between the light source and its surroundings, which can significantly affect visual comfort. High luminance contrast can lead to glare and visual discomfort, while moderate levels typically support comfort and visual clarity. This metric was particularly useful in assessing configurations where light sources were placed near reflective surfaces.

$$C = \frac{L_1 - L_2}{L_2} \tag{2}$$

where:

- C denotes luminance contrast,
- L_1 is the luminance of the light source (in $\mathrm{cd/m^2}$),
- L_2 is the luminance of the surrounding area (in $\mathrm{cd/m^2}$).

Measuring luminance contrast helped determine the potential for glare across configurations, allowing adjustments to mitigate discomfort in high-contrast scenarios.

3) Color Rendering Index (CRI) (Approximation): The CRI approximates how accurately colors are rendered under each lighting setup, which impacts ambiance and comfort. Though precise CRI calculations typically require specialized equipment, an approximation was calculated based on color difference measurements between test and reference illuminants. CRI is particularly relevant for living rooms, where accurate color perception is essential for aesthetics and mood.

$$\mathrm{CRI} = 100 - 4.6 \times \Delta E \tag{3}$$

where:

- ΔE represents the average color difference between the lighting setup and a reference illuminant.

The CRI approximation enabled evaluation of how well each lighting setup-maintained color fidelity, supporting a visually comfortable and aesthetically pleasing environment.

4) Perceived Brightness (B): Perceived brightness considers both illuminance and color temperature, as cooler lights (higher color temperatures) are often perceived as brighter. This subjective measure helped gauge participant responses to brightness under each configuration, mainly since perceived brightness can vary even with consistent illuminance levels.

$$B = E \times \frac{T}{6500} \tag{4}$$

where:
- B is the perceived brightness,
- E is the measured illuminance (in lux),
- T is the color temperature (in Kelvin).

Using perceived brightness as a metric allowed us to understand how lighting warmth influenced participant comfort, with higher color temperatures typically creating a sharper, more intense lighting environment.

5) Subjective Comfort Ratings: Besides quantitative measurements, subjective visual and physical comfort ratings were collected through participant surveys. Key aspects evaluated included:

- Visual Comfort: Assessed through brightness, glare, and shadow distribution ratings.
- Physical Comfort: Rated based on spatial warmth, relaxation, and perceived coziness.
- Ambiance: Rated on coziness and relaxation, plus suitability for various activities.

This combination of quantitative metrics and subjective feedback comprehensively evaluated lighting configurations' impact on comfort and ambiance, helping identify optimal residential placements.

4. Results

4.1. Visual comfort analysis

The data in **Table 2** and **Figure 2** reveals that lighting configurations differ significantly in brightness levels, consistency, and suitability for activities, depending on the light source placement and color temperature. Overhead lighting configurations, notably the Neutral (4000 K) setting with an average lux of 334.9 and low Standard Deviation (SD) of 12.7, provide the highest brightness consistency, making them highly suitable for visually intensive tasks such as reading. The Cool (6500 K) setting also supports reading and TV watching with a higher lux value of 295.4, although it has a slightly higher SD (17.4), suggesting a more significant variation in brightness that may introduce some visual discomfort over prolonged use. In comparison, wall-mounted configurations generally exhibit lower brightness levels, especially in the Warm (2700 K) and Cool (6500 K) settings, with average lux values of 212.6 and 238.3, respectively. These setups create a more ambient environment, ideal for socializing and relaxation, as they diffuse light more evenly and produce fewer shadows. The Warm (2700 K) wall-mounted light, with a low SD (10.6), provides consistent lighting suitable for relaxation, likely due to its softer, less intense illumination.

Table 2. Brightness consistency.

Lighting configuration	Average brightness (Lux)	SD (Lux)
Overhead [warm (2700K)]	283.7	15.3
Overhead [neutral (4000K)]	334.9	12.7
Overhead [cool (6500K)]	295.4	17.4
Wall-mounted [warm (2700K)]	212.6	10.6
Wall-mounted [neutral (4000K)]	256.8	14.8
Wall-mounted [cool (6500K)]	238.3	11.5
Floor/table lamp [warm (2700K)]	164.2	8.9
Floor/table lamp [neutral (4000K)]	182.9	9.3
Floor/table lamp [cool (6500K)]	172.4	7.4

Floor and table lamp configurations produce the lowest lux values, particularly the Warm (2700 K) and Cool (6500 K) settings, with average brightness levels of 164.2 and 172.4, respectively. These lower brightness levels are ideal for ambient lighting and activities that do not require high visual acuity, such as socializing and watching TV. The low SD in these settings indicates stable, diffused light that minimizes glare, contributing to a more comfortable and cozy ambiance for relaxation. Overall, the findings indicate that overhead lights with neutral or cool temperatures are best for tasks requiring high brightness, while wall-mounted and floor/table lamps with warm tones are preferred for activities focused on relaxation and ambiance. This differentiation allows optimal lighting configurations based on specific activities and comfort needs within residential spaces.

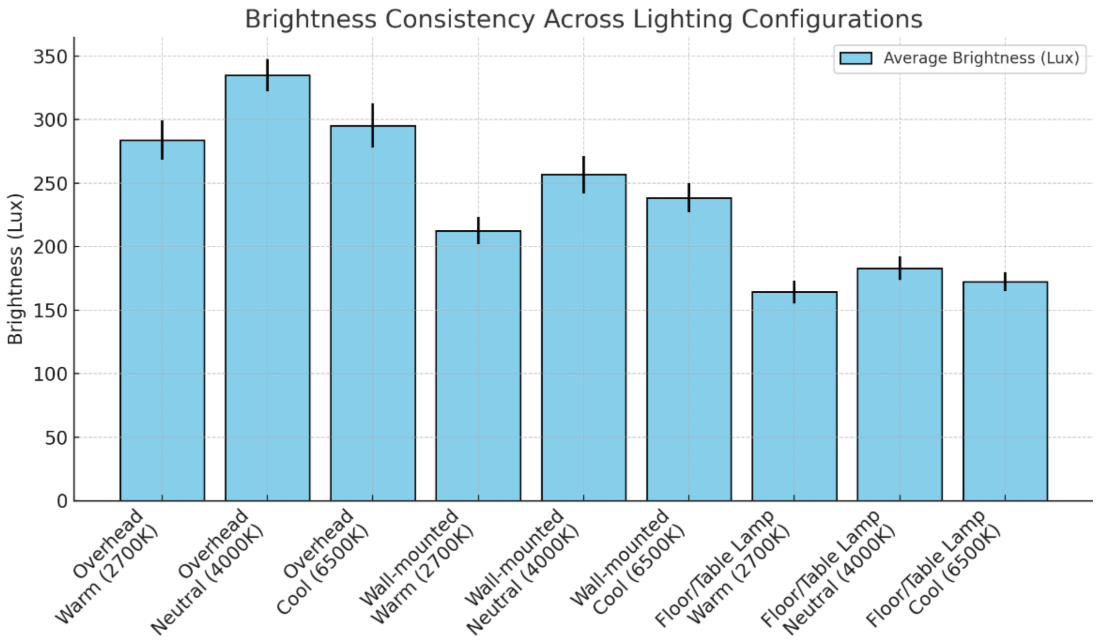

Figure 2. Brightness consistency results.

Table 3. Glare and shadow distribution results.

Lighting configuration	Average glare rating (1–5)	Average shadow rating (1–5)	Discomfort level
Overhead-warm (2700K)	3.8	4.0	Moderate
Overhead-neutral (4000K)	3.5	3.7	Moderate
Overhead-cool (6500K)	4.1	4.2	High
Wall-mounted-warm (2700K)	2.7	3.0	Low
Wall-mounted-neutral (4000K)	3.1	3.3	Moderate
Wall-mounted-cool (6500K)	3.3	3.5	Moderate
Floor/Table Lamp-warm (2700K)	2.1	2.2	Low
Floor/Table Lamp-neutral (4000K)	2.4	2.5	Low
Floor/Table Lamp-cool (6500K)	2.3	2.4	Low

The data in **Table 3** and **Figure 3** highlight how different lighting configurations affect glare and shadow presence, which are key factors in visual comfort. Overhead lighting setups, particularly with cool color temperatures (6500 K), received the highest ratings for glare (4.1) and shadow presence (4.2), resulting in a high discomfort level. This configuration's high glare and pronounced shadows likely contribute to visual strain, making it less suited for relaxing activities. The warm and neutral overhead settings (2700 K and 4000 K) scored moderately on glare and shadows, suggesting a more balanced light distribution with reduced visual discomfort, yet still not ideal for extended relaxation. Wall-mounted configurations showed moderate glare and shadow ratings in the neutral and cool settings, with averages around 3.1 to 3.5, suggesting some discomfort but significantly less than overhead lighting. The warm wall-mounted lighting (2700 K) had lower glare and shadow ratings (2.7 and 3.0), indicating a more comfortable setup for activities requiring minimal visual strain, such as socializing and relaxation. Wall-mounted lights generally diffused light more evenly, reducing sharp shadows and glare and enhancing comfort.

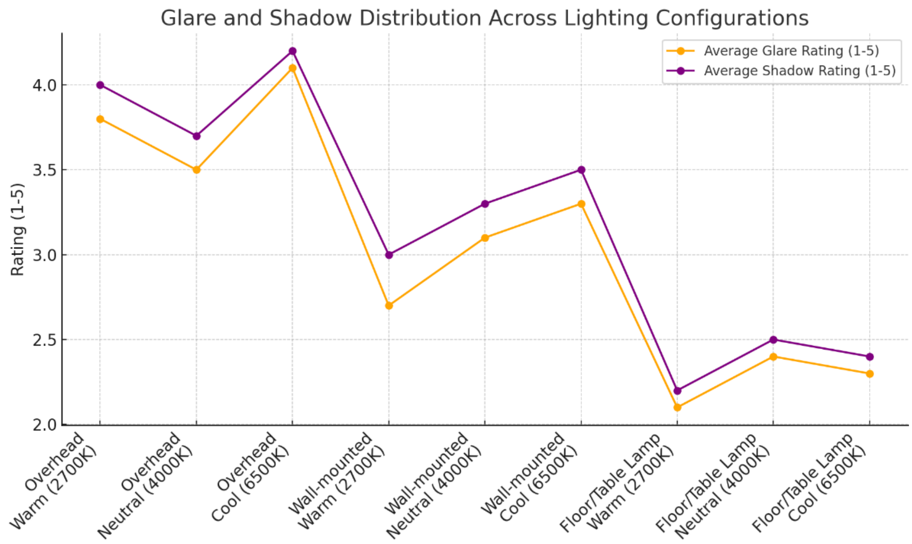

Figure 3. Glare and shadow analysis.

Floor and table lamp configurations had the lowest glare and shadow ratings across all color temperatures, ranging from 2.1 to 2.5, corresponding to low discomfort levels. These configurations are ideal for creating ambient, low-glare environments, making them preferable for relaxation and informal social activities. This pattern suggests that floor and table lamps, especially in warmer tones, provide a comfortable, glare-free ambiance for prolonged use without visual discomfort.

Table 4. Luminance contrast results.

Lighting configuration	Luminance of light source (cd/m²)	Luminance of surroundings (cd/m²)	Luminance contrast ratio (C)	Glare potential
Overhead-warm (2700K)	125.4	42.7	1.94	Moderate
Overhead-neutral (4000K)	147.2	50.1	1.94	High
Overhead-cool (6500K)	138.9	46.3	2.00	High
Wall-mounted-warm (2700K)	98.6	30.2	2.26	Moderate
Wall-mounted-neutral (4000K)	115.3	35.7	2.23	Moderate
Wall-mounted-cool (6500K)	107.8	32.6	2.31	Moderate
Floor/table lamp-warm (2700K)	87.3	22.4	2.90	Low
Floor/table lamp-neutral (4000K)	92.4	24.5	2.77	Low
Floor/table lamp-cool (6500K)	89.6	23.1	2.88	Low

Table 4 and **Figure 4** show luminance contrast ratios between light sources and surrounding areas, offering insights into glare potential and visual clarity. Overhead lighting setups, especially in neutral (4000 K) and cool (6500 K) temperatures, presented moderate to high luminance contrast ratios (1.94 to 2.00), with corresponding high glare potential. These configurations, particularly under cooler tones, may create strong contrasts that lead to glare and eye strain, thus limiting comfort for extended periods. The warm overhead setup (2700 K) had a moderate glare potential, with a contrast ratio of 1.94, indicating a somewhat softer transition between light and dark areas, which could reduce glare discomfort for some activities.

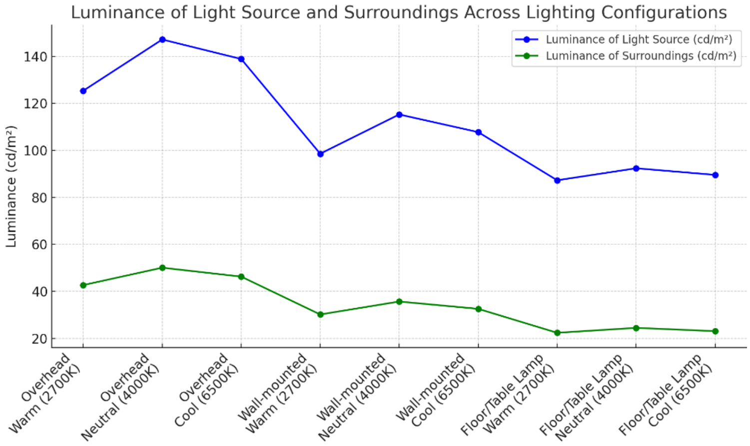

Figure 4. Luminance contrast analysis.

Wall-mounted configurations had moderate luminance contrast ratios ranging from 2.23 to 2.31, with moderate glare potential across color temperatures. This suggests that wall-mounted lights provide a balanced light distribution that supports adequate illumination without causing excessive contrast, making them suitable for general activities while maintaining moderate visual comfort. Floor and table lamp configurations demonstrated the highest luminance contrast ratios, particularly in the warm setting (2700 K) with a 2.90 ratio yet low glare potential. This pattern indicates that although floor and table lamps create distinct contrast zones, their low glare potential implies that these contrasts are softer and less disruptive to visual comfort. These configurations provide comfortable ambient lighting with minimal glare, suitable for relaxing and non-intensive visual activities.

4.2. Physical comfort analysis

Table 5 and **Figure 5** reveal distinct differences in perceived warmth and relaxation levels across lighting configurations, emphasizing the importance of lighting placement and color temperature in creating a comfortable environment. Overhead lighting in warm (2700 K) and neutral (4000 K) tones achieved high and moderate comfort levels, with warmth and relaxation ratings of 4.5 and 4.6 for the warm setting. However, the cool (650 0K) overhead lighting scored low in warmth (2.9) and relaxation (3.2), suggesting that cool-toned overhead lighting is less conducive to comfort, likely due to its harsher, more intense ambiance that may be perceived as less cozy.

Table 5. Perceived warmth and relaxation results.

Lighting configuration	Perceived warmth rating (1–5)	Perceived relaxation rating (1–5)	Comfort level
Overhead - warm (2700K)	4.5	4.6	High
Overhead - neutral (4000K)	3.8	4.0	Moderate
Overhead - cool (6500K)	2.9	3.2	Low
Wall-mounted - warm (2700K)	4.3	4.4	High
Wall-mounted - neutral (4000K)	3.5	3.8	Moderate
Wall-mounted - cool (6500K)	3.0	3.3	Moderate
Floor/table lamp - warm (2700K)	4.7	4.8	High
Floor/table lamp - neutral (4000K)	3.9	4.2	High
Floor/table lamp - cool (6500K)	3.1	3.4	Moderate

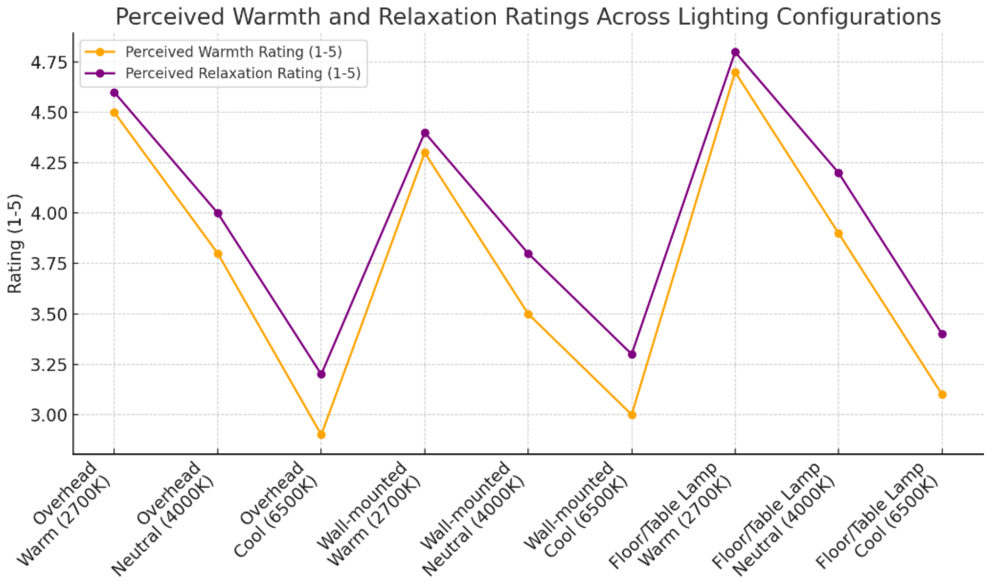

Figure 5. Perceived warmth and relaxation analysis.

Wall-mounted lighting generally provided moderate to high comfort levels, with the warm (270 0K) setting scoring highly for both perceived warmth (4.3) and relaxation (4.4). This configuration is particularly suited to spaces focused on relaxation and socializing, as wall-mounted warm lighting creates a soft, enveloping light that enhances comfort. The neutral and cool wall-mounted configurations were moderately comfortable, with scores in the 3.0–3.8 range, indicating that while they may support functionality, they are less effective in promoting a warm, relaxing ambiance. Floor and table lamps provided the highest levels of perceived warmth and relaxation, especially in warm (2700 K) and neutral (4000 K) tones, which achieved ratings of 4.7–4.8 for warmth and relaxation. These configurations are well-suited for creating a cozy, relaxing atmosphere, ideal for living spaces where comfort is prioritized. While slightly less comfortable, the cool (6500 K) setting still offered moderate relaxation (3.4), suggesting that even cooler-toned floor lighting can provide ambiance suitable for certain activities, though not as ideal for relaxation.

Table 6. Spatial perception results.

Lighting configuration	Perceived openness rating (1–5)	Perceived confinement rating (1–5)	Spaciousness level
Overhead [warm (2700K)]	3.7	2.3	Moderate
Overhead [neutral (4000K)]	3.9	2.1	Moderate
Overhead [cool (6500K)]	3.5	2.6	Low
Wall-mounted [warm (2700K)]	4.2	1.9	High
Wall-mounted [neutral (4000K)]	4.0	2.0	Moderate
Wall-mounted [cool (6500K)]	3.8	2.2	Moderate
Floor/table lamp [warm (2700K)]	4.5	1.6	High
Floor/table lamp [neutral (4000K)]	4.3	1.8	High
Floor/table lamp [cool (6500K)]	4.1	1.9	Moderate

Table 6 highlights the impact of lighting configurations on spatial perception,

showing that placement and tone significantly influence participants' sense of openness or confinement within a space. Overhead lighting configurations, particularly in neutral and warm tones (4000 K and 2700 K), achieved moderate spaciousness levels with perceived openness ratings of 3.7 and 3.9 and relatively low confinement ratings of 2.1–2.3. Cool-toned overhead lighting (6500 K) scored lower on perceived openness (3.5) and had a slightly higher confinement rating (2.6), indicating that cooler tones in overhead setups can create a more confined feeling, which may be less desirable in living room environments where spaciousness is preferred. Wall-mounted lighting in warm tones (2700 K) achieved the highest spaciousness level among all wall-mounted configurations, with an openness rating of 4.2 and low confinement (1.9), making it ideal for creating a more expansive, comfortable environment. Neutral and cool wall-mounted lights provided moderate spaciousness with ratings around 3.8–4.0 for openness and confinement ratings of 2.0–2.2, suggesting they maintain a balanced sense of space without creating confinement. These configurations are well-suited for versatile spaces that support both comfort and functionality.

From **Figure 6** is the Floor and table lamps, especially in warm (2700 K) and neutral (4000 K) tones, consistently provided the highest levels of perceived openness, scoring 4.5 and 4.3 in openness and as low as 1.6 in confinement. These configurations are optimal for creating a sense of spaciousness and comfort, reinforcing their suitability for relaxed, informal settings where ambiance and comfort are prioritized. The cool-toned (6500 K) floor lighting had a moderate effect on spaciousness, with an openness rating of 4.1 and confinement at 1.9, indicating it still maintains an open feel, though not as ideal for enhancing warmth.

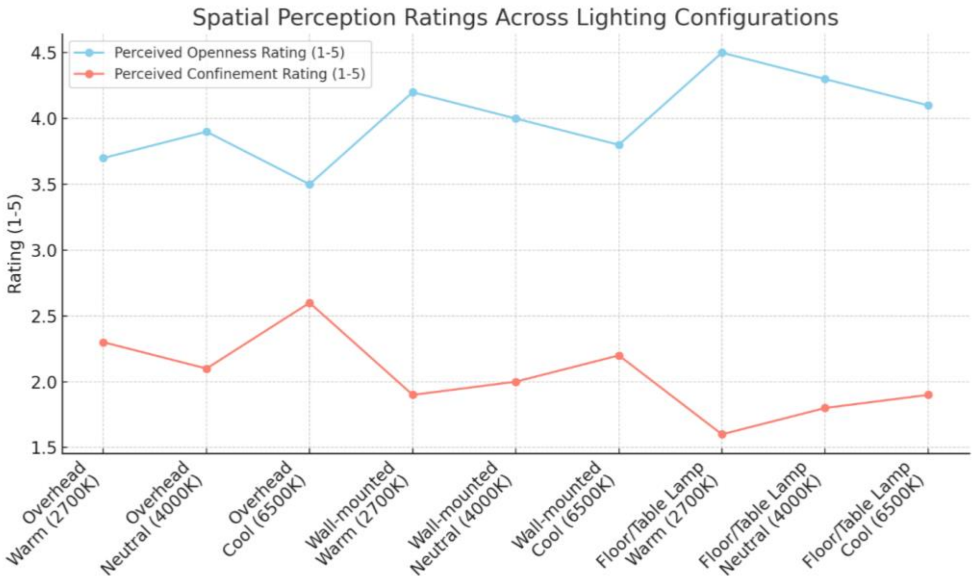

Figure 6. Spatial perception analysis.

4.3. Ambiance and activity suitability

Table 7 and **Figure 7** present participant ratings on the suitability of lighting configurations for various activities (reading, TV watching, and socializing). Overhead lighting configurations in warm (2700 K) and neutral (4000K) tones achieved the highest suitability ratings for reading, with scores of 4.3 and 4.6, respectively, indicating that overhead lighting provides focused brightness ideal for tasks that require visual clarity. The cool (6500 K) overhead lighting was rated highly for TV watching (4.4) but scored lower for socializing (3.9), suggesting that while cooler overhead lighting supports screen-based activities, it may not create an inviting atmosphere for interaction.

Table 7. Activity suitability ratings.

Lighting configuration	Reading suitability rating (1-5)	Tv watching suitability rating (1-5)	Socializing suitability rating (1-5)
Overhead-warm (2700 K)	4.3	3.8	4.5
Overhead-neutral (4000 K)	4.6	4.0	4.2
Overhead-cool (6500 K)	4.1	4.4	3.9
Wall-mounted-warm (2700 K)	3.5	4.2	4.6
Wall-mounted-neutral (4000 K)	3.8	4.5	4.3
Wall-mounted-cool (6500 K)	3.3	4.3	4.0
Floor/table lamp-warm (2700 K)	3.9	4.1	4.8
Floor/table lamp-neutral (4000 K)	4.2	3.9	4.4
Floor/table lamp-cool (6500 K)	3.7	4.2	4.1

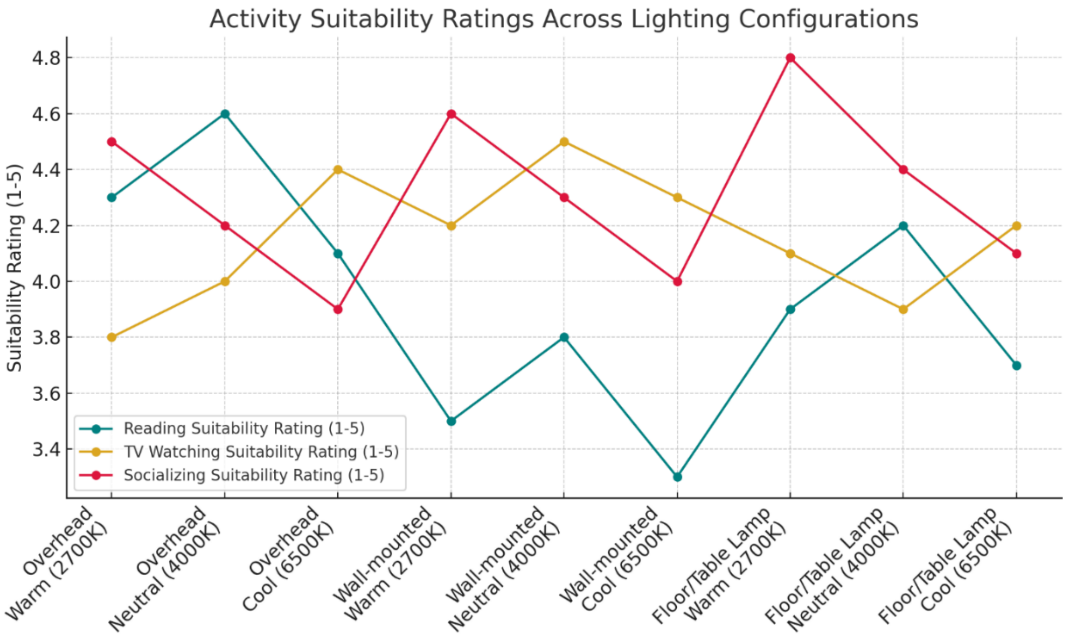

Figure 7. Activity rating.

Wall-mounted configurations offered high suitability for socializing, particularly in the warm (2700 K) tone, which received a rating of 4.6 for socializing and is thus recommended for activities that benefit from a warm and engaging ambiance. The neutral (4000 K) wall-mounted setup was versatile, scoring 4.5 for TV watching and 4.3 for socializing, indicating that it provides balanced lighting suitable for multi-functional spaces. Wall-mounted lighting in cool tones (6500 K) scored moderately across activities, suggesting that while it supports TV watching effectively (4.3), it may be less comfortable for activities requiring a warmer ambiance, such as reading or socializing.

Floor and table lamp configurations demonstrated the highest ratings for socializing and relaxation, particularly in warm (2700 K) and neutral (4000 K) tones. The warm setting was especially preferred for socializing (4.8) and was also suitable for reading (3.9), making it ideal for creating a cozy and relaxed setting. The neutral floor lighting achieved a balanced suitability rating across activities, with 4.2 for reading and 4.4 for socializing, further reinforcing its versatility in living spaces. The cool-toned (6500 K) floor and table lamp setup scored higher for TV watching (4.2) and moderately for socializing (4.1), suggesting that it can comfortably support screen-based and interactive activities but may lack the warmth preferred for reading.

Table 8. Ambiance ratings.

Lighting Configuration	Coziness Rating (1-5)	Relaxation Rating (1-5)
Overhead-warm (2700 K)	4.7	4.6
Overhead-neutral (4000 K)	4.3	4.4
Overhead-cool (6500 K)	3.6	3.8
Wall-mounted-warm (2700 K)	4.8	4.7
Wall-mounted-neutral (4000 K)	4.5	4.5
Wall-mounted-cool (6500 K)	4.0	4.1
Floor/table lamp-warm (2700 K)	4.9	4.8
Floor/table lamp-neutral (4000 K)	4.6	4.7
Floor/table lamp-cool (6500 K)	4.2	4.3

Table 8 and **Figure 8** present participant ratings on coziness and relaxation across different lighting configurations, assessing each setup's ability to create a welcoming and comfortable atmosphere. Overhead lighting in warm (2700 K) and neutral (4000 K) tones scored well in creating a welcoming environment, with coziness and relaxation ratings of 4.7 and 4.6 for the warm setting, marking it as "Very Welcoming." The neutral overhead setting also achieved a "Welcoming" ambiance level with ratings around 4.3–4.4. However, the cool (6500 K) overhead lighting rated lower on ambiance (3.6 for coziness and 3.8 for relaxation), indicating that cooler overhead lighting may create a less inviting atmosphere for relaxation-oriented activities.

Wall-mounted lighting, particularly in the warm (2700 K) tone, received the highest ambiance ratings (4.8 for coziness and 4.7 for relaxation), making it highly suitable for creating a warm, comfortable environment. This configuration supports social settings and relaxation by emitting a softer light closer to eye level. The neutral wall-mounted lighting setup also achieved high ratings (4.5 for coziness and relaxation), indicating that it maintains a welcoming atmosphere that can adapt to different uses. Cool wall-mounted lighting was perceived as "Comfortable" rather than "Welcoming," with ratings around 4.0–4.1, indicating it may lack the warmth preferred for a cozy atmosphere.

Floor and table lamp configurations achieved the highest ambiance scores, with warm (2700 K) and neutral (4000 K) tones creating a "Highly Comfortable" atmosphere. The warm floor lighting received nearly perfect ratings for coziness (4.9) and relaxation (4.8), making it ideal for settings focused on comfort and leisure. The neutral floor lighting followed closely with ratings of 4.6 for coziness and 4.7 for relaxation, reinforcing its suitability for relaxed and inviting settings. The cool-toned floor lighting scored lower (4.2 for coziness and 4.3 for relaxation) yet was still considered "Comfortable," showing that even cooler tones in floor lighting can provide comfort, though they may lack the warm ambiance offered by other configurations.

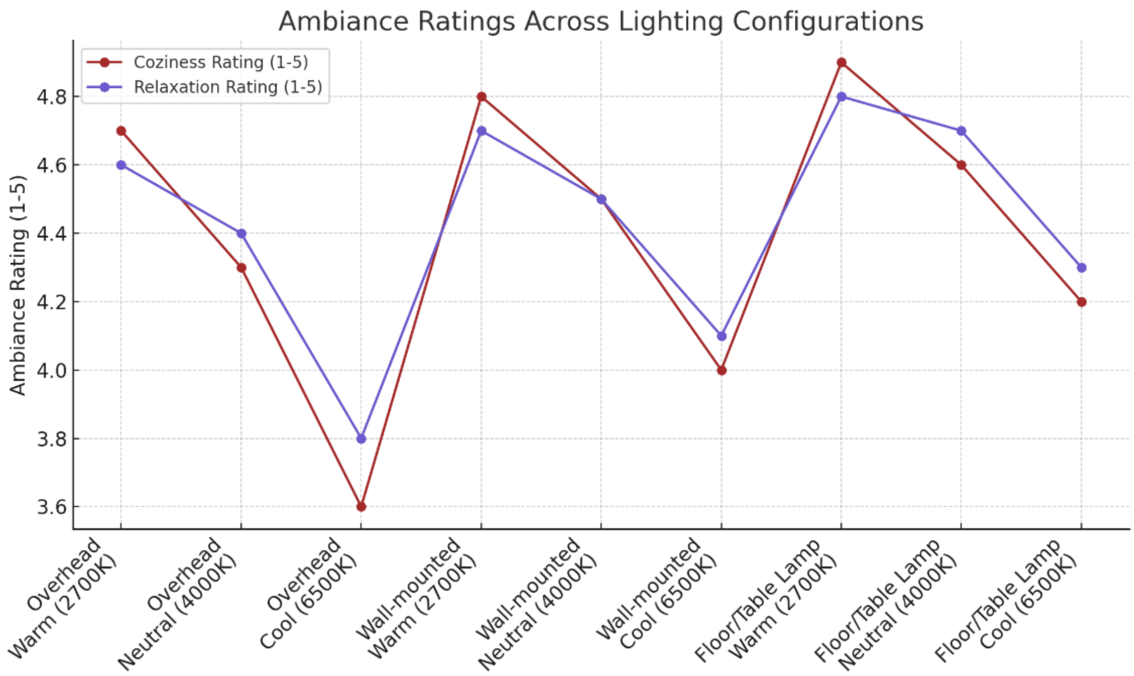

Figure 8. Ambiance ratings.

4.4. Comparison of color temperature effects

Table 9 and **Figure 9** illustrate the impact of color temperature on overall comfort and perceived ambiance. Warm lighting (2700 K) achieved the highest ratings in both comfort (4.7) and ambiance (4.8), with a perceived warmth level of "High." This setup was rated as "Highly Comfortable," indicating that warm tones are particularly effective in creating a cozy, inviting atmosphere ideal for relaxation. The high comfort level associated with warm lighting suggests its suitability for living areas where comfort and warmth are prioritized. Neutral lighting (4000 K) received moderately high ratings, with a comfort rating of 4.3 and an ambiance rating of 4.4, which translates to a perceived warmth level of "Moderate" and an overall comfort level of "Comfortable." This color temperature provides a balanced lighting effect, neither warm nor too cool, making it suitable for general-purpose lighting where a welcoming yet functional ambiance is needed. Its moderate warmth makes neutral lighting adaptable to social and task-oriented residential activities.

Table 9. Comfort ratings across color temperatures.

Color temperature	Average comfort rating (1–5)	Average ambiance rating (1–5)	Perceived warmth level	Overall comfort level
Warm (2700 K)	4.7	4.8	High	Highly Comfortable
Neutral (4000 K)	4.3	4.4	Moderate	Comfortable
Cool (6500 K)	3.6	3.7	Low	Moderate

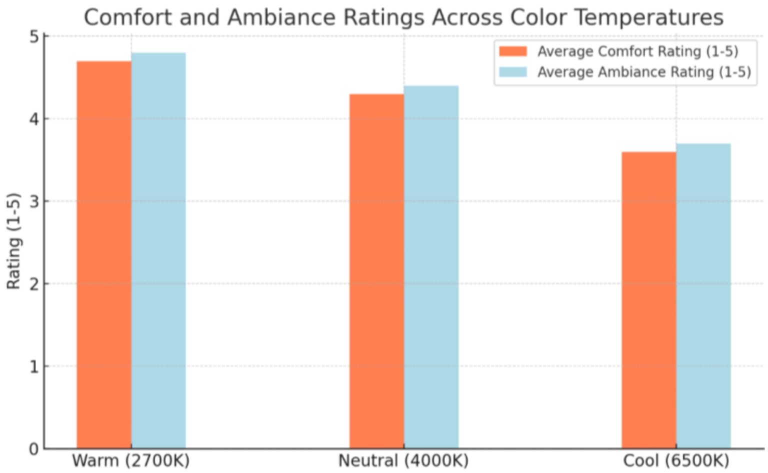

Figure 9. Comfort ratings across color temperatures.

Cool lighting (6500 K) scored the lowest on both comfort (3.6) and ambiance (3.7), with a perceived warmth level of “Low” and an overall comfort level of “Moderate.” The relatively low scores indicate that cool lighting is less adequate in creating a warm and inviting atmosphere. However, it may still have practical applications in settings where brightness and alertness are prioritized over comfort, such as task lighting for workspaces within a residential setting. Overall, the findings suggest that warm lighting (2700 K) is optimal for creating a highly comfortable and relaxing environment, while neutral lighting (4000 K) provides a balanced option for ambiance and functionality. Cool lighting (6500 K), while effective for clarity, is less suitable for comfort-focused areas in a residential context.

Table 10. Brightness perception results.

Color temperature	Perceived brightness rating (1–5)	Visual clarity rating (1–5)	Comfort level for brightness
Warm (2700 K)	3.9	4.0	Moderate
Neutral (4000 K)	4.2	4.3	Comfortable
Cool (6500 K)	4.6	4.5	High

Table 10 and **Figure 10** examines how color temperature affects perceived brightness and visual clarity, highlighting differences in comfort associated with each lighting tone. Cool lighting (6500 K) received the highest ratings for both perceived brightness (4.6) and visual clarity (4.5), with a high comfort level for brightness. This setup is well-suited for tasks requiring high visual clarity, as the cooler tone increases the brightness perception, making it ideal for activities that demand attention to detail. However, its intensity may be less conducive to relaxation-focused environments. Neutral lighting (4000 K) achieved moderately high ratings in perceived brightness (4.2) and visual clarity (4.3), providing a

comfortable balance. This setup's comfort level associated with brightness is "Comfortable," suggesting that neutral lighting balances adequate brightness and comfort. This makes it suitable for multi-functional areas where relaxation and functionality are desired, such as living rooms for socializing and light reading. Warm lighting (2700 K) scored lower on perceived brightness (3.9) and visual clarity (4.0), with a "Moderate" comfort level for brightness. While warm lighting may be less adequate for tasks requiring high brightness, its moderate brightness and clarity levels enhance comfort, supporting a cozy atmosphere for activities that do not require intense lighting. Its moderate brightness perception aligns well with the desire for a softer, more relaxing ambiance in residential settings.

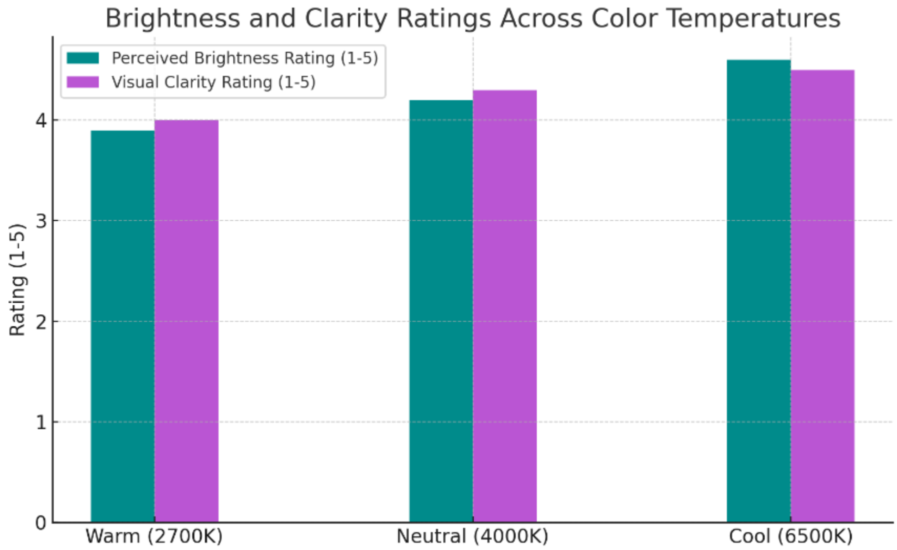

Figure 10. Brightness and clarity analysis.

4.5. CRI and color perception accuracy

Table 11 and **Figure 11** explore the impact of lighting configurations and color temperatures on color rendering accuracy, as measured by the Color Rendering Index (CRI) and participant ratings of color fidelity and visual appeal. A higher CRI indicates better color rendering quality, crucial for spaces where accurate color perception is valued, such as residential living areas. Overhead lighting configurations in warm (2700 K) and neutral (4000 K) tones demonstrated high color rendering capabilities, with CRI values of 92.5 and 90.1, respectively, and high color fidelity ratings (4.5–4.7). This indicates that warm and neutral overhead lighting provides satisfactory color accuracy and is visually appealing, making it suitable for residential environments where both ambiance and accurate color perception are essential. However, overhead lighting in the cool (6500 K) tone had a lower CRI (87.6) and a moderate color fidelity rating (4.2), indicating that while it provides adequate color rendering, it may fall short in creating a vibrant, natural ambiance compared to warmer tones.

Table 11. Color rendering accuracy results.

Lighting configuration	Color rendering index (CRI)	Color fidelity rating (1-5)	Visual appeal level
Overhead-warm (2700K)	92.5	4.7	High
Overhead-neutral (4000K)	90.1	4.5	High
Overhead-cool (6500K)	87.6	4.2	Moderate
Wall-mounted-warm (2700K)	93.4	4.8	Very High
Wall-mounted-neutral (4000K)	91.3	4.6	High
Wall-mounted-cool (6500K)	88.9	4.3	Moderate
Floor/table lamp-warm (2700K)	94.0	4.9	Very High
Floor/table lamp-neutral (4000K)	92.0	4.7	High
Floor/table lamp-cool (6500K)	89.2	4.4	Moderate

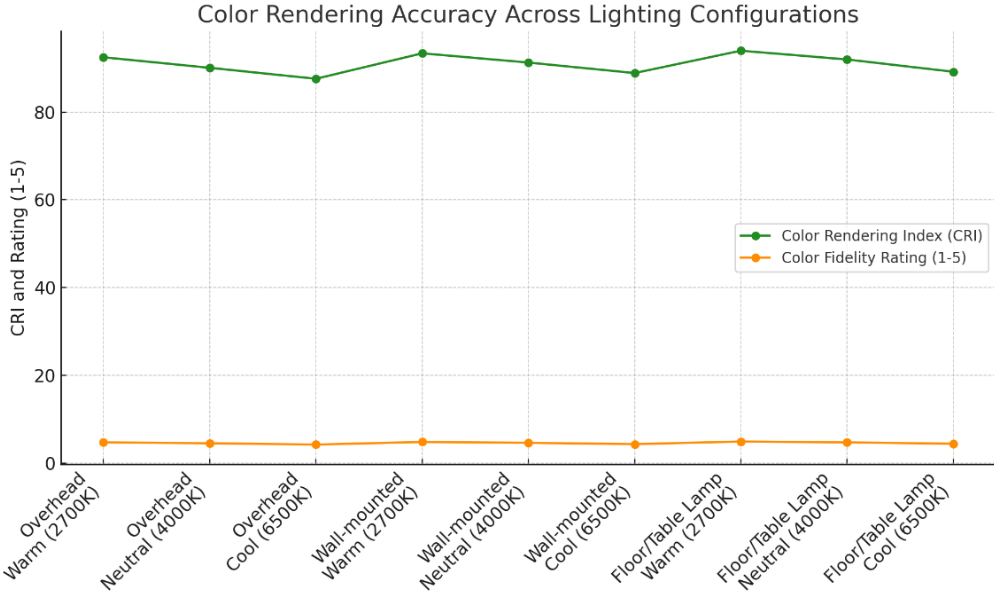

Figure 11. Color rendering accuracy.

Wall-mounted lighting in warm and neutral tones scored very well, with a CRI of 93.4 and 91.3 and color fidelity ratings of 4.8 and 4.6, respectively. The "Very High" visual appeal level for warm wall-mounted lighting suggests that this configuration is particularly effective in maintaining natural, true-to-life color perception, making it ideal for living spaces focused on relaxation and socializing. The cool-toned wall-mounted lighting (6500 K), while still providing moderate appeal with a CRI of 88.9 and a fidelity rating of 4.3, maybe less adequate for applications with vibrant color accuracy. Floor and table lamp configurations performed best overall, especially in the warm (2700 K) setting, which achieved the highest CRI (94.0) and color fidelity rating (4.9), earning a "Very High" visual appeal level. This makes warm floor lighting highly suitable for creating a comfortable, visually appealing space with excellent color rendering. The neutral tone (4000 K) floor lighting also scored highly (CRI of 92.0 and fidelity rating of 4.7), supporting its versatility for multi-functional residential spaces. Even the cool-toned (6500 K) floor lighting, with a moderate CRI of 89.2 and fidelity rating of 4.4, maintains a comfortable level of color accuracy suitable for ambient lighting needs.

4.6. Subjective feedback and preference rankings

Table 12 and **Figure 12** provides insights into participants' preferences for lighting configurations based on average preference rankings. Floor/table lamps and wall-mounted configurations in warm tones (2700 K) received the highest rankings, with average scores of 4.8 and 4.7, respectively, making them the "Most Preferred" setups. These configurations were highly favored for their cozy ambiance, perceived warmth, and suitability for relaxing activities, indicating that warm-toned, lower-level lighting is ideal for residential spaces focused on comfort and social interaction. Floor/table lamp configurations also performed well in neutral tones (4000 K), achieving a "Highly Preferred" status with an average preference ranking of 4.6, making it the third-most preferred setup. The preference for neutral lighting in floor and table lamps suggests that participants value this configuration for its versatility in balancing warmth and functional brightness, which suits social and task-oriented activities within a comfortable ambiance.

Table 12. Participant preferences.

Lighting configuration	Average preference ranking (1–5)	Preference level	Overall rank
Overhead [warm (2700K)]	4.5	Highly preferred	4
Overhead [neutral (4000K)]	4.2	Preferred	6
Overhead [cool (6500K)]	3.8	Moderate	9
Wall-mounted [warm (2700K)]	4.7	Most preferred	2
Wall-mounted [neutral (4000K)]	4.3	Preferred	4
Wall-mounted [cool (6500K)]	3.9	Moderate	8
Floor/table lamp [warm (2700K)]	4.8	Most preferred	1
Floor/table lamp [neutral (4000K)]	4.6	Highly preferred	5
Floor/table lamp [cool (6500K)]	4.1	Preferred	7

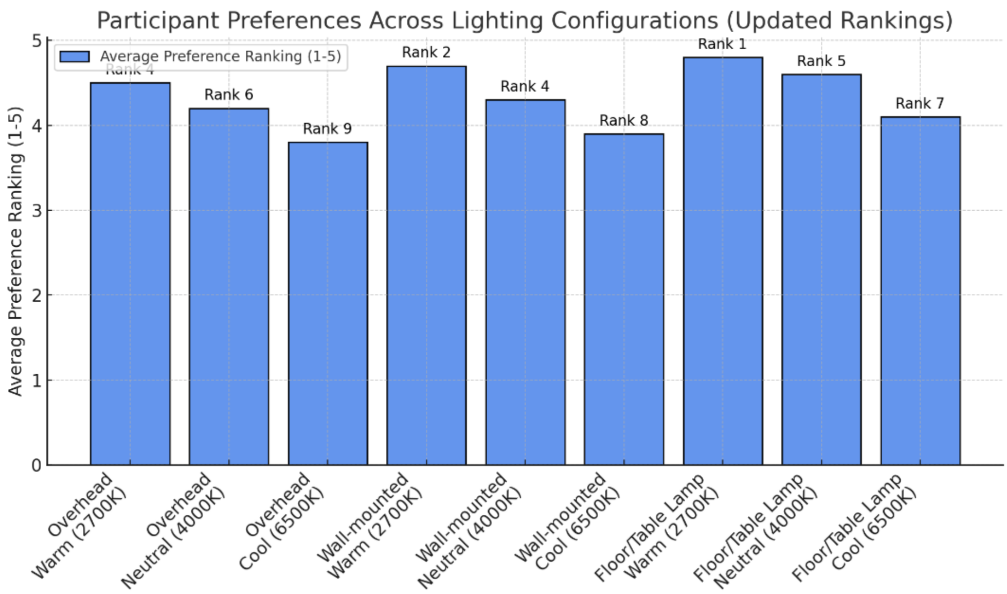

Figure 12. Participant preferences.

Overhead and wall-mounted lighting in warm (2700 K) and neutral (4000 K) tones also scored well, with preference rankings ranging from 4.2 to 4.5. Overhead warm lighting received a "Highly Preferred" level with an average rating of 4.5 (Ranked 2), showing that overhead lighting can still appeal when warmer tones are used, as they mitigate glare and provide a pleasant, inviting environment. Neutral tones in wall-mounted configurations were also well-received (Ranking 4), offering a flexible option for general-purpose lighting in living areas. Cool-toned lighting (6500 K) was generally less favored across all configurations, with preference ratings of 3.8 to 4.1. Overhead and wall-mounted cool lighting ranked lowest, indicating that participants found these configurations less comfortable or inviting for residential spaces. Cool tones were seen as less suitable for relaxing or cozy environments, suggesting they are more appropriate for task-focused lighting rather than social or relaxation areas within the home.

5. Conclusion and future work

This study demonstrates the significant role of lighting placement and color temperature in influencing visual and physical comfort within residential living room settings. Examining a range of lighting configurations reveals that different placements and color temperatures contribute uniquely to the ambiance, clarity, and overall comfort, supporting varied activities commonly performed in living rooms. Warm-toned floor and table lamps (2700K) achieved the highest ratings for perceived warmth and relaxation, highlighting their suitability for creating a cozy, inviting atmosphere for socializing and leisure. In contrast, cool-toned overhead lighting (6500 K) provided enhanced visual clarity, making it more appropriate for tasks requiring focus, such as reading. Wall-mounted lighting in neutral tones (4000 K) emerged as a versatile solution, balancing comfort and functionality to support various activities without compromising ambiance. This configuration's moderate warmth and brightness make it a practical option for spaces that serve multiple purposes. These findings underscore the importance of selecting lighting that aligns with specific activity needs and user preferences, enabling adaptable and comfortable living environments. The insights gained from this study contribute to a more nuanced understanding of residential LD, emphasizing that optimal lighting solutions should consider both placement and color temperature to enhance functionality and comfort.

Future research could expand on these findings by exploring personalized, dynamic lighting systems that adjust based on real-time activity and occupant preferences. Such advancements could support adaptable, user-centered lighting in residential spaces, promoting well-being and enhancing the home experience across diverse living environments.

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