A Study on the Visual Comfort of Urban Building Colors under Overcast and Rainy Weather

Yihe Li, Binqing Xu and Yang Liu *

School of Art and Design, Zhejiang Sci-Tech University, Hangzhou 311199, China; liyihe594@163.com (Y.L.); xubinqing422@gmail.com (B.X.)
* Correspondence: graceliu@zstu.edu.cn; Tel.: +86-130-6785-5166

Abstract: The color of urban architecture plays a crucial role in influencing the visual comfort of city inhabitants. During overcast and rainy conditions, there is a noticeable shift in how people perceive the comfort level of building colors and their visual recognition. This research selects Hangzhou, a city renowned for its prevalent overcast rainy weather in China, gathering 60 samples across two distinct architectural types. It encompasses 120 architectural images captured during both overcast rainy and clear days. Furthermore, color values were extracted utilizing the Chinese architectural color card, adhering to the Munsell color system. As an empirical approach, a survey was conducted, enlisting 40 participants for a questionnaire assessment based on the Likert scale. Following descriptive analysis of the data, SPSS was utilized to conduct correlation analysis and regression analysis, unveiling the relationship between visual comfort and color attributes (hue, value, chroma). Subsequently, RStudio was employed to analyze the threshold of architectural color comfort, comparing overcast rainy weather with clear weather. The findings suggest a significant correlation between the value contrast of architectural colors and visual comfort during overcast rainy weather. Concerning value, the visual comfort threshold for residential buildings is within the range of $7 \leq \text{value} < 10$ and $3 \leq \text{value contrast} < 5$, whereas for commercial buildings, it is within the range of $4 \leq \text{value} < 7$ and $3 \leq \text{value contrast} < 5$. Regarding chroma, there is no correlation between chroma contrast and commercial buildings, while the visual comfort threshold for residential buildings lies within the range of $0 \leq \text{chroma} < 4$ and $4 \leq \text{chroma contrast} < 8$.

Keywords: overcast and rainy weather; urban architecture color; visual comfort; Munsell color system

1. Introduction

Good color planning can bring a high-quality visual environment to the city [1]. With rapid economic growth and accelerated urbanization, people’s experience of urban environments is increasingly negative, becoming a severe global issue [2]. In this context, some researchers are increasingly aware that the comfort of architectural colors is a positive factor affecting the environment and people’s preferences [3,4], which can stimulate people’s subconscious and cognitive aesthetic pleasure [5]. However, color is a complex dynamic phenomenon; it depends on the light color environment [6]. With the change in weather, buildings are constantly affected by factors such as lighting and environmental color [7,8], the color properties of buildings (hue, value, chroma) show great differences [9–11], and people’s visual perception of architectural color also changes accordingly. Particularly in certain countries and regions, prolonged and persistent rainy weather can lead to reduced environmental visibility, causing visual recognition difficulties [12]. This results in anxiety and stress among residents [13,14], subtly affecting the visual comfort of urban dwellers and potentially even impacting their psychological health further [2,15–17]. Therefore, in order to enhance the urban visual environment and harness the positive effects of color on perception [18], improving the visual comfort of urban architectural colors in overcast and rainy weather conditions is an urgent issue to be addressed in current urban color planning.
Visual comfort in this study is defined according to the European standard EN 12665, which defines visual comfort as “the subjective state of visual health caused by the visual environment” [19]. It is a comprehensive indicator for evaluating the satisfaction of the residents’ visual experience of the spatial environment [20]. Although this concept is inherently a relatively subjective psychological experience, comfort feelings such as “comfortable” and “uncomfortable” can intuitively reflect significant differences in individuals’ perception of visual comfort [21]. This assists in understanding the interactive relationship between the visual environment and human perception and provides architects and planners with a powerful reference to optimize architectural color design. Currently, research on visual comfort primarily focuses on exploring factors related to the relationship between a series of human needs and the light environment, such as the quantity of light, the uniformity of light, and the quality of light in terms of color rendition [22]. Numerous studies frequently employ the daylight factor as a benchmark for evaluating the visual comfort performance of buildings. However, this metric is a static indicator based on the geometric shape of buildings, making it difficult to assess the variations in outdoor daylight illuminance on buildings under natural lighting conditions [23]. Therefore, research on architectural visual comfort has, to date, primarily focused on studying the impact of indoor lighting environments and daylight conditions on the visual comfort of occupants [24–27]. For instance, many studies have examined the relationship between lighting distribution within office spaces and visual comfort [28,29], while some research has investigated the effect of architectural facade elements, such as window openings and spatial geometries, on visual comfort and satisfaction [3,30]. There is an increasing body of research indicating that the comfort of outdoor spaces significantly affects human activities. Reducing uncomfortable outdoor conditions can have a positive impact on individuals and enhance urban vitality [13,31]. However, research on the correlation between color factors, which occupy a significant proportion in the outdoor architectural environment, and visual comfort is relatively scarce. Recent studies have examined people’s visual experiences of seasonal color changes in the environment [32], and scholars have investigated the history, culture, and aesthetics of architectural colors to improve the coordination and comfort between these colors and their surrounding environments [33]. Nevertheless, research on how changes in architectural color properties under natural conditions such as weather factors specifically affect people’s visual comfort remains insufficient. This limits our in-depth understanding of the complex relationships between weather, color, and visual comfort. Therefore, in the color planning and design of building exteriors, we should not only consider the comfortable lighting of clear weather but also delve into the actual impact of changes in architectural color properties under overcast and rainy conditions on people’s visual comfort. Corresponding measures should be taken to optimize the planning and design of architectural colors, thereby enhancing people’s positive experiences of urban spaces.

This study investigates the variation in architectural colors using weather conditions and building type as the main variables for architects to more fully grasp and correctly utilize these color priorities and how they affect visual comfort in their designs. Using a combination of subjective research and objective experimentation, the effect of color attributes of buildings on visual comfort is investigated. The experiment utilized a Chinese architectural color card based on the Munsell color system to collect and compare color data of residential and commercial buildings under overcast rainy and clear weather conditions. Participants were surveyed through questionnaires, and their ratings of the building samples were statistically analyzed. These subjective scores will serve as a reference for evaluating the visual comfort of architectural colors. Subsequently, the study utilizes correlation and regression analysis methods to analyze the relationships between visual comfort and various color attributes. Finally, RStudio is used to analyze the threshold ranges for the comfort levels of architectural colors under the influence of weather conditions. The paper establishes primary objectives: (1) to investigate the impact of different weather conditions on visual comfort, (2) To identify and verify the color factors affecting residential
and commercial buildings in Hangzhou, and (3) to analyze the threshold values for visual comfort of the main influencing factors.

2. Data and Methods

2.1. Research Design

The methodological steps of this study were primarily divided into two parts (Figure 1). The first part involved the initial sampling of building colors. Architectural color samples were collected from the experimental site, which required setting uniform color measurement conditions such as observation distance, observation time, and tools. Then, based on the Munsell color model system, color attributes such as value (V), chroma (C), value contrast (VC), and chroma contrast (CC) were organized for the color samples. Subsequently, the color variation trends of the main and secondary colors of commercial and residential buildings under different weather conditions (overcast rainy and clear days) were visually presented. The second part involved experiments on color visual comfort. Uniform conditions for indoor experiments were set, controlling indoor humidity, temperature, and noise environment. Participants were then invited to rate the visual comfort of images of the architectural color samples in the laboratory. The participants’ ratings were quantified and analyzed, and Pearson correlation analysis was used to examine the relationship between visual comfort and color attributes. Based on this analysis, stepwise linear regression analysis was employed to further determine the main factors influencing visual comfort. Finally, after identifying the important factors affecting visual comfort in different building types, RStudio was used to analyze the threshold ranges between key color elements—value (V), chroma (C), value contrast (VC), chroma contrast (CC)—and visual comfort.

![Figure 1. Methodology and workflow.](image)

2.2. Study Area

Hangzhou is in the northern part of Zhejiang Province, China, and has a subtropical monsoon climate, characterized by abundant rainfall throughout the year. Statistics indicate that during the period from 2010 to 2023, Hangzhou experienced overcast and rainy weather for up to 60% of the year (Figure 2). Therefore, Hangzhou, where overcast and rainy weather is relatively frequent, was chosen as the site for this research. The architectural samples used in the experiments were selected from Hangzhou’s densely populated districts of Xihu, GongShu, and Binjiang. Images of residential and commercial buildings were collected from these three districts (Figure 3). Residential and commercial buildings, which account for a significant proportion of urban land use, are the most common types of structures composing the urban landscape. Hence, the study selected residential and commercial buildings to investigate the potential impact of architectural colors on visual comfort under overcast and rainy conditions, allowing for a more targeted optimization of building types.
Figure 2. Weather distribution in Hangzhou 2013–2023. (Note: Due to the different total number of days each year, the total number of some years varies from 100%).

Figure 3. Sample collection site.

2.3. Data Acquisition and Processing

This study evaluated the visual comfort of building colors in overcast rainy weather, using the photographic method employed by French colorist Jean-Philippe Lenclos to collect building samples [34]. The digital camera used for shooting was a Canon with 26.2 megapixels. The photoshoot took place from October to November, from 10:00 a.m. to 2:00 p.m., during which the sun moved from 30 degrees southeast to 30 degrees southwest. Specific shooting times under clear weather were on 15 October, with the sun’s elevation angle decreasing from 44.01 degrees to 39.49 degrees, and on 23 October, from 41.6 degrees to 37.00 degrees. The selection of shooting days was based on meteorological industry standards, which consider the percentage of the sky covered by clouds as the criterion. Clear days are characterized by 0% to 10% cloud cover, 10% to 30% is considered partly cloudy, 30% to 70% is regarded as cloudy, and more than 70% is seen as overcast. Consequently, photography on cloudy and rainy days was conducted under conditions with more than 70% cloud cover and rainfall of ≥0.1 mm. Photography on clear days was carried out with 0% to 10% cloud cover and no rainfall. Additionally, to maintain the consistency of architectural color comparison across different weather conditions, it is necessary to standardize other consistent shooting conditions [35]. Therefore, fixed-distance shooting at 0.5 km was adopted both on overcast rainy and clear days, with the sampling time set from 10:00 a.m. to 2:00 p.m. to avoid the interference of daylight color temperature on architectural color sampling during early morning and evening measurements, which may cause errors in test data [36]. At the same time, the camera was set to the same focal length, exposure, and sensitivity for each shoot [37]. In the initial photography session, a total of 74 colored photos of residential and commercial buildings were collected. During this process, to ensure the selection of suitable and high-quality images, further screening was conducted among the selected colored photos. After removing invalid and severely backlit photos, 120 effective architectural images were obtained, consisting of 60 residential...
buildings and 60 commercial buildings photographed under overcast rainy and clear conditions, respectively (Figure 4).

In the field of visual comfort research, brightness and brightness contrast are widely considered to be among the key parameters, especially when discussing the impact of illumination on visual comfort. The measurement unit for brightness is typically expressed in the international unit cd/m² as the standard [38]. However, this study focused on the color properties of buildings. For this purpose, during the color data extraction phase, the research utilized the China Architectural Color Card (GB/T18922-2008 [39]) based on the Munsell color system standard, which categorizes the color attributes of the main and secondary colors of buildings into hue (H), value (V), and chroma (C). Following this, the study adopted a methodology that integrates the color card comparison approach with computerized color recognition. This study combined the use of a color card comparison method with computerized color recognition. Initially, four researchers with a background in design used the Munsell-based China Architectural Color Card (CBCC) for color matching at the shooting site. After the shoot, the colormatch software was used to accurately identify the main and secondary colors of the buildings in the images. Subsequently, the colors were extracted using design software like InDesign2021 and Adobe Illustrator2022,
ensuring that the HSB color values matched those in the electronic version of the China Architectural Color Card. The researchers then compared and calibrated the computer-generated values against the color values visually estimated on site. Then, four researchers separately correlated and calibrated the color values obtained from the computer with those compared through visual inspection on site. This method took into account not only the buildings’ inherent colors but also the color conditions influenced by the environment, enabling a more thorough representation of the buildings’ “true color conditions” [40]. Previous studies have shown that in the analysis of perceived relationships, value and chroma are more potent indicators. The impact of hue on visual comfort is weaker than that of value and chroma [36,41]. Therefore, this study no longer focused on the discussion of hue (H) and hue contrast (HC) on visual comfort conditions. In the Munsell color system, value can be divided into 11 levels from 0 to 10, with the maximum value of 10 representing ideal white and the minimum value of 0 representing ideal black. Munsell chroma is divided into values from 0 to 12, with the minimum of 0 maximum value of 10 representing ideal black. Munsell chroma is divided into values from 0 to 12, with the minimum of 0 representing pure gray without any color tendency, and the maximum of 12 indicating the most vivid and saturated colors (Figure 5). After organizing the architectural samples, to extract the color data of the architectural samples, color values similar to the main and secondary colors of the architectural samples were selected from the electronic version of the China Architectural Color Card. According to the scale of thresholds for architectural color attributes, value (V) includes high value range (Vh) (7 ≤ V < 10), medium value range (Vm) (4 ≤ V < 7), and low value range (Vl) (0 ≤ V < 4). Furthermore, main and secondary colors form a value contrast (VC) relationship, i.e., nine tones: high–long tone, high–medium tone, high–short tone, medium–long tone, medium–medium tone, medium–short tone, low–long tone, low–medium tone, and low–short tone. That is, VC includes long tone (VCl) (5 ≤ VC ≤ 9), medium tone (VCm) (3 ≤ VC < 5), and short tone (VCs) (0 ≤ VC < 3). Chroma ranges include high chroma range (Ch) (8 ≤ C ≤ 12), medium chroma range (Cm) (4 ≤ C < 8), and low chroma range (Cl) (0 ≤ C < 4). Correspondingly, the chroma relationships of main and secondary colors are categorized into vivid–strong, vivid–medium, vivid–weak, medium–strong, medium–medium, medium–weak, gray–strong, gray–medium, and gray–weak. Chroma contrast (CC) is divided into strong CC (CCs) (8 ≤ CC ≤ 12), medium CC (CCm) (4 ≤ CC < 8), and weak CC (CCw) (0 ≤ CC < 4) [36,42,43]. It should be emphasized that in order to select the typical architectural color samples of residential and commercial buildings in Hangzhou, the inherent colors of the architectural samples were divided into main colors, auxiliary colors, and decorative colors according to the color area ratio of the architectural samples [40]. This research mainly adopted the value, chroma, and difference between the main and auxiliary color values of the target building. Descriptive statistics were determined as color attribute factors that affect visual comfort. However, due to the small number of decorative color samples collected, decorative colors were filtered in this study.

Figure 5. Value range of V and VC, and C and CC.

2.4. Experimental Conditions and Procedures

The experiment unfolded within a low-light laboratory, covering an area of roughly 52 square meters. The laboratory setup included a long table and chairs designated for experimental purposes (Figure 6). The low-light laboratory was extensively shaded with blackout curtains, effectively eliminating the penetration of natural light. Research indi-
cates that external factors, such as the view through a window and room temperature, can significantly affect the perception of glare discomfort [43,44]. Additionally, environmental parameters like temperature, humidity, and air ionization have been shown to impact various subjective responses, including thermal comfort, perceived air quality, alertness, and overall well-being [45]. Before initiating the tests, the indoor environment was regulated to maintain a steady temperature range of 23–26 °C, with noise levels kept at 45 ± 5 dB, and relative humidity was adjusted to fall between 40% and 60%. To display the architectural images, we used a liquid crystal display (LCD) screen that measured 3100 mm by 2300 mm and featured a resolution of 1920 × 1200. The images, formatted as Microsoft PowerPoint slides, were projected onto this screen using a laser projection device. This arrangement was selected to ensure a uniform viewing experience for all participants, thereby guaranteeing that the assessment of architectural images remained consistent throughout the study.

Figure 6. Elevation of laboratory room.

The use of photographs to address questions regarding architectural facades, environments, and preferences has been validated [46]. Thus, this study investigated the relationship between the color properties of building exteriors and people’s visual comfort through a photographic questionnaire survey. After explaining the concept of visual comfort (from uncomfortable to comfortable) and obtaining informed consent, participants were asked to rate the sample images on a five-point scale (1–5). To familiarize participants with this process, two practice slides were shown for rating before the start of the experiment, which were not included in the data analysis. This procedure aimed to ensure all subjects began the experiment under similar and familiar conditions, thereby minimizing potential biases [47]. During the presentation of architectural images, to evoke participants’ objective perception of the same building under different weather conditions, images of buildings under overcast rainy weather conditions and normal weather conditions were presented alternately. Research has shown that human perception of the lighting environment primarily relies on instantaneous perception of the surroundings [27]. Therefore, during this experiment, the slideshow was set to play automatically, with each slide displayed for 5 s to avoid potential effects due to overly long or short viewing times. Finally, participants completed a questionnaire survey while viewing the slides.

2.5. Questionnaire Design and Participants

The study selected a total of 60 architectural samples, comprising residential and commercial buildings, to serve as visual stimuli for assessing visual comfort. Each participant received two copies of the official questionnaire, aimed at evaluating their sense of visual comfort due to the different visual perceptions that building colors under various weather conditions can induce. Thus, the survey required participants to rate the visual comfort of 120 images of residential and commercial buildings under overcast and clear weather conditions using a Likert scale of 1–5 (1 = “not very comfortable”, 2 = “uncomfortable”, 3 = “neutral”, 4 = “comfortable”, 5 = “very comfortable”). It is crucial to precisely control confounding variables such as the participants’ age, gender, background, and environmental factors to ensure an experiment’s accuracy [48]. Therefore, the subjects were as homogenous as possible in terms of age and education level [26]. Consequently, all par-
Participants in this study were students from Zhejiang Sci-Tech University, as they are more adaptable to training and following experimental procedures. Ultimately, the experiment recruited 40 undergraduate students from universities in Hangzhou to participate in this research. The participants’ ages ranged from 20 to 25 years, with a gender distribution of 27% male (n = 11) and 73% female (n = 29). All subjects had normal color vision capabilities. The study obtained 40 valid questionnaires in the end, with others excluded due to uncontrolled variables.

At the experiment’s initial stage, all participants were asked to fill out an online survey to collect their gender, age, education, major, and any nearsightedness. Those with vision impairments were required to participate using their usual vision correction devices. No participants were excluded from the experiment due to vision problems. All tests were conducted in one room. After providing verbal and written instructions to the participants, and once they indicated they understood the task, the experiment commenced.

2.6. Data Analysis Methods

The data in this study were analyzed using SPSS 27 and RStudio 2023 software, with the sample’s data summarized through metrics such as mean and standard deviation. Ratings given by each participant for each building sample were collected and statistically analyzed. This process determined the average comfort score for each of the 120 images and assessed the differences in brightness and chroma under various weather conditions, where no extreme values were detected. The study identified the visual comfort ratings under cloudy and sunny conditions as the dependent variables. Initially, it examined the variations in brightness and chroma of the buildings across different weather conditions. Subsequently, to explore the effects of variables such as the value (V) and chroma (C) of main colors, the value (V) and chroma (C) of secondary colors, as well as the contrasts in value (VC) and chroma (CC) on visual comfort in various weather conditions, both correlation and regression analyses were performed. These analyses were designed to determine the strength of the association between each independent variable and the dependent variables. Lastly, RStudio was utilized to determine the threshold of visual comfort for both overcast rainy and normal weather conditions, setting a comfort rating of 3 (3 = “neutral”) as the benchmark.

3. Results

3.1. Trend Analysis of Value and Chroma of Architectural Colors

Based on the collected data, a comparative analysis was conducted on the trends in value and chroma of main and secondary colors for two types of buildings under different weather conditions. The analysis revealed that for both residential and commercial buildings under clear weather conditions, the value and chroma of main and secondary colors were higher than on overcast rainy days. The value of main and secondary colors for both types of buildings generally fell within a medium–high range of 6–8, while the chroma of main and secondary colors was typically within a low range of 0–4. Among these, the value of the main color in residential buildings and the chroma of the secondary color in commercial buildings showed greater variability with weather conditions, while the chroma of the main color in residential buildings and the value of the main color in commercial buildings showed less variation. Trend analysis also indicated that the variability in value of main and secondary colors was relatively greater for residential buildings than for commercial buildings. Conversely, the variability in chroma in main and secondary colors was relatively greater for commercial buildings than for residential buildings. Overall, the color value of residential buildings was slightly higher than that of commercial buildings, while the overall color saturation of commercial buildings was lower than that of residential buildings. Notably, under clear weather conditions, when the chroma value of a building sample measured 0, it remained essentially stable, even in overcast rainy weather conditions (Figure 7).
commercial buildings showed less variation. Trend analysis also indicated that the variability in value of main and secondary colors was relatively greater for residential buildings than for commercial buildings. Conversely, the variability in chroma of main and secondary colors was relatively greater for commercial buildings than for residential buildings. Overall, the color value of residential buildings was slightly higher than that of commercial buildings, while the overall color saturation of commercial buildings was lower than that of residential buildings. Notably, under clear weather conditions, when the chroma value of a building sample measured 0, it remained essentially stable, even in overcast rainy weather conditions (Figure 7).

![Residential building main value](image1)
![Residential building main chroma](image2)
![Residential building secondary value](image3)
![Residential building secondary chroma](image4)

![Commercial building main value](image5)
![Commercial building main chroma](image6)
![Commercial building secondary value](image7)
![Commercial building secondary chroma](image8)

Figure 7. Trends in the value and chroma of main and secondary colors of architectural colors under overcast rainy and clear weather conditions: (a) residential buildings; (b) commercial buildings.

3.2. Correlation Analysis between Color Attributes and Architectural Visual Comfort

Correlation is a commonly utilized metric to quantify the degree of linear relationship between two variables [49]. In the process of identifying the independent variables that influence visual comfort, we categorized the color attributes according to the Munsell color model. By converting the hue (H), value (V), and chroma (C) of architectural images into color values found in the Chinese Architectural Color Card, we established a framework comprising ten color-related elements of interest, including weather and visual comfort. These elements are the main color hue, secondary color hue, main color value, secondary color value, main color chroma, and secondary color chroma, along with value contrast and chroma contrast. It is important to highlight that in the process of sample collection, buildings utilizing accent colors constituted a lower proportion of the architectural images...
gathered. Moreover, existing research on color and visual comfort has indicated that hue contrast exerts a weaker impact on visual comfort. Consequently, we excluded hue contrast (HC) and decorative colors in our correlation analysis [36,37].

Initially, through the use of bivariate correlation analysis, we explored the strength of the association between each of the eight chosen color attributes and visual comfort. The results, as depicted in (Figure 8), show that in the first group of residential buildings, the main color chroma (C) \((r = 0.51, p < 0.05)\), secondary color chroma (C) \((r = 0.37, p < 0.01)\), value contrast (VC) \((r = 0.47, p < 0.01)\), chroma contrast (CC) \((r = 0.37, p < 0.01)\), and weather \((r = 0.73, p < 0.01)\) were positively correlated with visual comfort, demonstrating significant associations. The main color hue, main color value (V), secondary color hue, and secondary color value were not related to the visual comfort of residential buildings. In the second group of commercial buildings, the main color value (V) \((r = 0.35, p < 0.01)\), secondary color chroma (C) \((r = 0.36, p < 0.01)\), value contrast (VC) \((r = 0.53, p < 0.01)\), chroma contrast (CC) \((r = 0.41, p < 0.01)\), and weather \((r = 0.83, p < 0.01)\) were positively correlated with visual comfort. However, the main color hue (H), main color chroma (C), secondary color hue (H), and secondary color value (V) were not associated with the visual comfort of commercial buildings. Based on these findings, to more accurately measure the impact of relevant independent variables on the dependent variable and thus identify the key factors influencing the color visual comfort of residential and commercial buildings, we conducted stepwise regression analysis using SPSS version 27. This calculated standardized regression coefficients with adjusted \(R^2\) values (VIF < 2). Subjective ratings of visual comfort for residential and commercial buildings were used as the dependent variable, incorporating all significant independent variables identified from the correlation analysis. Regression analysis revealed that the critical factors affecting the color visual comfort of residential buildings included weather \((p < 0.000)\), value contrast (VC) \((p \leq 0.002)\), and chroma contrast (CC) \((p \leq 0.003)\) (Table 1). For commercial buildings, the significant factors were weather \((p < 0.000)\) and VC \((p < 0.000)\) (Table 2).

![Figure 8. Pearson correlation analysis between color attributes and visual comfort: (a) Pearson correlation analysis between color attributes and visual comfort in residential buildings; (b) Pearson correlation analysis between color attributes and visual comfort in commercial buildings.](image-url)
Table 1. Residential building stepwise regression analysis.

<table>
<thead>
<tr>
<th></th>
<th>Unstandardized Coefficient</th>
<th>Standardization Coefficient</th>
<th>t</th>
<th>p</th>
<th>Collinear Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Standard Error</td>
<td>Beta</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Constant)</td>
<td>2.147</td>
<td>0.078</td>
<td>27.620</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Weather</td>
<td>0.093</td>
<td>0.029</td>
<td>3.233</td>
<td>0.002</td>
<td>1.108</td>
</tr>
<tr>
<td>VC</td>
<td>0.073</td>
<td>0.023</td>
<td>3.140</td>
<td>0.003</td>
<td>1.033</td>
</tr>
</tbody>
</table>

R² = 0.639

R² partial is the correlation coefficient after controlling for other variables.

Table 2. Commercial building stepwise regression analysis.

<table>
<thead>
<tr>
<th></th>
<th>Unstandardized Coefficient</th>
<th>Standardization Coefficient</th>
<th>t</th>
<th>p</th>
<th>Collinear Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Standard Error</td>
<td>Beta</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Constant)</td>
<td>2.339</td>
<td>0.053</td>
<td>43.822</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Weather</td>
<td>0.714</td>
<td>0.066</td>
<td>10.838</td>
<td>0.000</td>
<td>1.129</td>
</tr>
<tr>
<td>VC</td>
<td>0.108</td>
<td>0.026</td>
<td>4.157</td>
<td>0.000</td>
<td>1.129</td>
</tr>
</tbody>
</table>

R² = 0.758

R² partial is the correlation coefficient after controlling for other variables.

3.3. Visual Comfort Recognition Thresholds of VC, CC

Following the regression analysis, numerical statistics were conducted on the key factors affecting residential and commercial buildings. The color values for value contrast (VC) and chroma contrast (CC) in residential buildings, as well as value contrast (VC) in commercial buildings, were tabulated under two weather conditions: overcast rainy and clear. Using RStudio, we further analyzed the distribution range of visual comfort thresholds for the two types of buildings. The analysis, illustrated in Figure 9, indicates that under overcast rainy conditions, the visual comfort of both residential and commercial buildings predominantly fell in the “uncomfortable” level. Conversely, under clear weather conditions, participants’ visual experiences were more positive, with the visual comfort of both residential and commercial buildings primarily within the “comfortable” distribution range. This underscores the significant impact of weather conditions on the variation in architectural color attributes and their effect on people’s visual comfort. However, under overcast rainy conditions, the comfort level of residential buildings was generally higher than that of commercial buildings. When the main color value of residential buildings was in the high value range (7 ≤ V < 10) and medium value range (4 ≤ V < 7), the visual comfort was generally close to the neutral comfort level of “3”. For commercial buildings, when the value was in the medium range (4 ≤ V < 7), it was relatively close to the neutral comfort level of “3”.

Additionally, under clear weather conditions, both residential and commercial buildings exhibited a stable comfort threshold within the neutral comfort level of “3” and close to the comfortable level of “4” when the value contrast (VC) was in the mid-range (3 ≤ VC < 5). Under overcast rainy conditions, despite the general discomfort associated with the value contrast thresholds for both residential and commercial buildings, comfort levels were closer to “neutral comfort” when VC was in the lower range (0 ≤ VC < 3) compared to other threshold ranges. In terms of chroma contrast, residential buildings under overcast rainy conditions approached the neutral comfort level of “3” when chroma (C) was in the low range (0 ≤ C < 4). Conversely, under clear weather conditions, the chroma of residential buildings in the low range (0 ≤ C < 4) was primarily above the neutral comfort level of “3”. The results of the threshold analysis indicate that visual comfort is most stable when the color value of buildings is in the mid- to high range, with value contrast in the mid-range. Chroma in the low range and weaker chroma contrast can lead to a more positive and stable impact on visual comfort.
Figure 9. Visual comfort thresholds for value contrast (VC) and chroma contrast (CC): (A) visual comfort thresholds for value contrast (VC) and chroma contrast (CC) in residential buildings; (B) visual comfort threshold for value contrast (VC) in commercial buildings.
4. Discussion

4.1. Effects of Luminance Contrast (VC) and Chromaticity Contrast (CC) on Visual Comfort

In the realm of visual comfort research, extensive investigations have explored the influence of daylight illumination and lighting quality on indoor visual comfort. However, unlike the stable and controllable conditions of indoor environments, the visual comfort in outdoor settings is markedly more vulnerable to fluctuations in natural light caused by weather variations. Addressing this gap, the present study delves into the influence of architectural color attributes on visual comfort in outdoor environments, examining how variations in weather conditions affect these dynamics. We identified a positive correlation between both value and chroma contrasts with visual comfort, while the influence of hue was found to be minimal. This finding corroborates the work of Noguchi and Liu Y et al., who highlighted the predominance of value and chroma over hue in affecting visual comfort [36,41]. Furthermore, Noguchi’s observation that high illumination and color temperature stimulate the sympathetic and central nervous systems not only supports our results but also underlines the intricate relationship between architectural color, emotional states, and well-being. Through regression analysis, this study further confirms that value contrast is a principal factor affecting the color visual comfort of both residential and commercial buildings. However, in commercial buildings, chroma contrast’s impact on subjective visual comfort ratings was not found to be significant. This outcome underscores the priority of enhancing value contrast in cities that experience prolonged periods of overcast and rainy weather. The differing performances of chroma contrast in the analysis of the two types of buildings may be attributed to the distinct characteristics inherent to different architectural types. For example, commercial buildings often incorporate extensive use of glass as a design element, which affects the manifestation of color chroma in this material. Additionally, studies have shown that value primarily influences visibility, while color temperature has a more pronounced effect on ambiance [50]. Therefore, the visual identification obstacles brought by overcast and rainy weather are precisely what impact the visibility of spatial environments, likely contributing to the greater importance of value contrast over chroma contrast in this study. Furthermore, existing research has demonstrated that in outdoor lighting environments, visual comfort is more significantly affected by value than by chroma [51]. This study found that within color attributes, value contrast, which has a strong correlation with illumination, was the most significant factor influencing visual comfort. This reaffirms that the primary determinant of visual comfort is lighting conditions [27,52], and individuals’ perception of spatial environments is largely influenced by the interplay between light and color [53]. This outcome may be attributable to the fact that visual discomfort is related to specific times of the day and certain weather conditions [54]. Therefore, in the design and planning of architectural colors, for buildings in cities that experience prolonged periods of overcast and rainy weather, priority should be given to enhancing visual comfort through the consideration of value contrast (VC). Additionally, architectural color design should thoroughly consider local cultural and climatic characteristics. We believe that categorizing buildings by region and evaluating visual comfort accordingly can enhance the appeal of specific places when designing and applying colors, thereby improving the visual quality of urban environments in various areas.

In recent years, scholars have concentrated on exploring the variations in visual environmental characteristics across different spatial types, as well as the significant associations between individual visual comfort and a variety of environmental factors within these spaces [55]. However, color, as an environmental variable, often goes overlooked despite its critical role in shaping the visual environment. Our research aimed to address this gap by highlighting the subtle impacts of color on visual comfort. The findings reveal the potential of value and chroma contrasts to enhance the visual comfort of architectural colors. Optimizing architectural color attributes, especially by increasing value contrast, can effectively improve the visual comfort of outdoor environments, which may in turn have positive effects on individuals’ psychological, physical, and health well-being. It is
hoped that these insights can aid urban planners, architects, and real estate developers in better understanding the impact of weather on visual comfort satisfaction. We believe that improving and enhancing the visual comfort of the color environment can have psychological, physical, and health impacts. Furthermore, visual comfort is considered a major factor affecting issues such as low-energy architectural design and urban street thermal comfort [56]. Designers can leverage this understanding to delve deeper into visual comfort within the ecological environment. The more we understand about this process and the intervening variables, the better we can design spaces that positively influence human behavior.

4.2. Strategies for Enhancing the Visual Comfort of Architectural Colors in Overcast Rainy Weather

Statistical analysis revealed significant differences in the visual comfort of architectural colors under overcast rainy and clear weather conditions, with visual comfort ratings obtained under clear weather generally ranking higher than those during overcast rainy conditions. Buildings with higher value and lower chroma contrast in clear weather conditions tended to achieve better visual comfort. Moreover, under overcast rainy conditions, the visual comfort of commercial buildings was slightly lower than that of residential buildings. Based on the findings of this study, we offer the following recommendations for stakeholders:

1. Participant rating data indicate that architectural colors with high value levels ($7 \leq V < 10$), mid-range value contrast ($3 \leq VC < 5$), medium to low chroma ($3 \leq C \leq 6$), and low chroma contrast ($0 \leq CC < 4$) generally had a positive effect on visual comfort. Therefore, in urban color planning, appropriate color samples can be selected based on the color values of the Chinese Architectural Color Card. Avoiding colors with low value and high chroma can help alleviate visual stress among residents during prolonged overcast and rainy weather.

2. Based on the distribution of thresholds and considering the value contrast that affects both types of buildings, commercial buildings exhibited slightly lower visual comfort than residential buildings under both overcast rainy and clear weather conditions. This discrepancy may arise from fundamental variations in material selection and facade design between the two architectural types. Previous research has indicated that visual comfort tends to deteriorate with increased reflectivity, and the use of natural materials with low reflectivity can reduce glare in buildings [1]. This phenomenon is especially pronounced in urban commercial buildings, where facade materials typically have high reflectance properties, such as glass and stainless steel. These materials are known for their substantial glare capabilities, which can negatively impact visual comfort and degrade the overall quality of the visual environment. Furthermore, the functional demands and operational characteristics of commercial architecture often necessitate enhanced transparency and visual allure, thereby driving the prevalence of high-reflectance materials in these settings. Consequently, it is imperative for architects and designers to rigorously assess the optical properties and visual implications of building materials during the design process. By doing so, they can significantly improve the visual comfort of the structures, aligning with both aesthetic values and functional efficacy.

3. The results of the regression analysis indicate that the primary factors affecting the visual comfort of the two types of buildings differed, revealing that commercial buildings are less influenced by chroma contrast compared to residential buildings. Overall, under changing weather conditions, both residential and commercial buildings are influenced by value contrast. Thus, in the design and planning process of architectural colors, architects and designers can consider prioritizing the enhancement of value contrast. It must also be emphasized that, although the results of this study indicate that hue was not the primary factor determining color visual comfort, numerous studies have found that hue significantly affects emotions. Therefore, in the process
of making design decisions, we must not overlook the potential psychological impact of hue on individuals.

4.3. Limitations

The focus of this study was the impact of changes in building facade colors on visual comfort under different weather conditions. As such, other visual elements in the scene, such as the sky, roads, and landscapes, were not included in the research. This may have led to an oversight of the potential contributions of these elements to overall visual comfort. Although we employed a controlled method from the same viewing distance during the experimental photography process to minimize interference from roads and other landscape elements, thus focusing on the visual effects of building colors, future research will still need to consider these factors. It will be necessary to better control and analyze the mixed variables in the visual scene, providing a solid scientific basis for architectural color design. Additionally, numerous studies have shown that weather changes can induce complex emotional and psychological changes. Although our results provide clues for improving visual comfort through color attributes, they do not demonstrate the relationship between architectural color under weather changes and the psychological health, emotions, and visual stress of urban residents. In the design of our questionnaire, we were unable to draw conclusions about specific symptoms related to psychological health from the participants’ rating tests. Future research could more appropriately and deeply investigate the complex connections between different weather conditions and emotions, as well as psychological health and well-being. Moreover, due to the diverse geographical and climatic characteristics of different cities, there are variations in the color characteristics, external forms, and facade materials of buildings. Additionally, in the process of sample collection, it is inevitable that the actual appearance of buildings will be affected by natural erosion, leading to material aging, color fading, and unevenness. In addition, although this study adopted a rigorous process for selecting architectural color values, based on the characteristics of real-space environments and human visual perception, the method of measuring color cards on-site followed by computer software analysis for color quantification and extraction reduced the error in visual identification to some extent during the color quantification process. However, it is still limited by the precision of the equipment, and the results of color selection may still differ from the actual architectural colors in the environment. Lastly, Hopkinson’s research on visual comfort defines it as follows: “The term visual comfort is taken to mean the absence of a sensation of physiological pain, irritation, or distraction. It is not intended to cover the aesthetic sensation of pleasure or dislike of the surroundings [57]”. This definition points out to us that in addition to visual comfort as a subjective state of visual well-being induced by the visual environment of architectural color, architectural color may also induce feelings of irritation, distraction, and other feelings about the visual environment in which it is located. In addition to the subjective state of health as the visual environment of architectural color, architectural color may also cause people to have feelings of stimulation and distraction of the visual environment where they are located. This part was not studied in this paper, and it is expected to be supplemented in subsequent studies.

5. Conclusions

In cities experiencing long periods of continuous overcast and rainy weather, architectural color design should consider the impact of weather conditions on the visual comfort of urban residents. To determine the differences in visual comfort brought about by changes in architectural colors under overcast rainy weather, this paper focused on residential and commercial buildings in Hangzhou, China, collecting questionnaire ratings from 40 participants. Based on the Chinese Architectural Color Card, color attributes of 120 architectural samples were extracted, categorizing colors starting from and secondary colors. A total of nine factors affecting visual comfort were identified, and the relationship between these factors and subjective evaluations of visual comfort was established through
bivariate correlation analysis and regression methods. Comfort thresholds for different building types under overcast rainy and clear weather conditions were analyzed. The results indicate:

(1) The changes in color attributes under different weather conditions had a significant impact on the visual comfort of residential and commercial buildings in Hangzhou. Hue (H) showed no correlation with the visual comfort of either residential or commercial buildings. In residential buildings, the main color (C), secondary color (C), and contrasts in value and chroma were positively correlated with visual comfort. In commercial buildings, the main color value (V), secondary color chroma (C), value contrast (VC), and chroma contrast (CC) were positively correlated with visual comfort. After regression analysis, it was further discovered that the main factors influencing the visual comfort of residential and commercial buildings in Hangzhou differed. The visual comfort of residential building colors was more influenced by value contrast (VC) and chroma contrast (CC), whereas commercial buildings were more affected by value contrast (VC).

(2) Based on the threshold analysis, the value contrast (VC) for both residential and commercial buildings often fell within the range of $0 \leq \text{VC} < 3$. The chroma contrast (CC) for residential buildings was frequently found to be in the range of $4 \leq \text{CC} < 8$. When the value contrast threshold of residential buildings was in the mid-range ($3 \leq \text{VC} < 5$), they were more likely to achieve a more stable and positive visual comfort, regardless of whether it was overcast rainy weather or clear weather. In clear weather, commercial buildings displayed a relatively positive visual comfort when the VC threshold was either $\text{VCM} (3 \leq \text{VC} < 5)$ or $\text{VCs} (0 \leq \text{VC} < 3)$.

(3) Among the architectural samples collected in this study, there was a lack of samples with value contrast in the high range ($5 \leq \text{VC} \leq 9$) and chroma contrast in the strong range ($8 \leq \text{CC} \leq 12$). This indicates that the overall architectural colors in Hangzhou are characterized by lower saturation and more stable illumination on building facades.

This study offers a referable method for evaluating the comfort level of urban architectural colors under overcast rainy conditions. From a design perspective, these findings can assist designers in making informed architectural color design decisions, further optimizing the visual quality of urban spaces and enhancing people’s experiences and comfort in urban environments.

Author Contributions: Conceptualization, Y.L. (Yihe Li) and B.X.; methodology, Y.L. (Yihe Li); software, Y.L. (Yihe Li) and B.X.; validation, Y.L. (Yihe Li), B.X. and Y.L. (Yang Liu); formal analysis, Y.L. (Yihe Li); investigation, Y.L. (Yihe Li) and B.X.; resources, Y.L. (Yang Liu); data curation, Y.L. (Yihe Li) and B.X.; writing—original draft preparation, Y.L. (Yihe Li); writing—review and editing, Y.L. (Yihe Li); visualization, Y.L. (Yihe Li) and B.X.; supervision, Y.L. (Yang Liu); project administration, Y.L. (Yihe Li) and B.X.; funding acquisition, Y.L. (Yang Liu). All authors have read and agreed to the published version of the manuscript.

Funding: This study was financed by the Planning Fund of the Ministry of Education of China (project number: 20YJAZH072) and the National Social Science Fund Project of China (project number: 21BZX125).

Data Availability Statement: Dataset available on request from the authors.

Conflicts of Interest: The authors declare neither conflicts of interest nor competing interests.

References


9. Liu, J.; Wang, Q. Study on Building Materials and Building Color Attribute Changes in Cold Regional for Weather Factors and Distance. AMR 2014, 1014, 263–266. [CrossRef]


20. Jakubiec, J.A.; Reinhart, C.F. A Concept for Predicting Occupants’ Long-Term Visual Comfort within Daylit Spaces. LEUKOS 2016, 12, 185–202. [CrossRef]


22. Fabi, V.; Andersen, R.; Corgnati, S. Accounting for the Uncertainty Related to Building Occupants with Regards to Visual Comfort: A Literature Survey on Drivers and Models. Buildings 2016, 6, 5. [CrossRef]


