White LEDs in Landscape Lighting Application

Insiya Shakir and Nadarajah Narendran
Lighting Research Center
Rensselaer Polytechnic Institute, Troy, NY 12180

White LEDs in Landscape Lighting Application

Insiya Shakir* and Nadarajah Narendran
Lighting Research Center, Rensselaer Polytechnic Institute, Troy, NY 12180

ABSTRACT

A laboratory experiment was conducted to understand the acceptability of different white light emitting diodes (LEDs) for outdoor landscape lighting. The study used a scaled model setup. The scene was designed to replicate the exterior of a typical upscale suburban restaurant including the exterior façade of the building, an approach with steps, and a garden. The lighting was designed to replicate light levels commonly found in nighttime outdoor conditions. The model had a central dividing partition with symmetrical scenes on both sides for side-by-side evaluations of the two scenes with different light sources. While maintaining equal luminance levels and distribution between the two scenes, four types of light sources were evaluated. These include, halogen, phosphor white LED, and two white light systems using RGB LEDs. These light sources were tested by comparing two sources at a time placed side-by-side and by individual assessment of each lighting condition. The results showed that the RGB LEDs performed equal or better than the most widely used halogen light source in this given setting. A majority of the subjects found slightly dimmer ambient lighting to be more typical for restaurants and therefore found RGB LED and halogen light sources to be more inviting. The phosphor white LEDs made the space look brighter, however a majority of the subjects disliked them.

Keywords: LED, white light, landscape/exterior lighting, spectral power distribution, and preference.

INTRODUCTION

The goal of this study was to understand the acceptability of different white light emitting diodes (LEDs) for outdoor landscape lighting applications. The reasons for lighting the exterior of a building and its immediate surrounding landscape may vary in degree between functional and aesthetic needs. The lighting requirements for functional needs call for a certain amount of illumination so that people can enter and exit a building safely. However, the lighting for aesthetics could vary significantly depending on individual preferences.

The application addressed in this study is the exterior of the building and landscape lighting such as in pathways, steps, flowerbeds, and small shrub lights. It does not include parking lots or street lighting. The components that make up an exterior landscape environment are foliage, walkways, steps, sculptures, signage, exterior facades, and other architectural elements. A lighting specifier considers each of these components when selecting the light sources and designing the lighting. The nature of the task to be performed in the outdoor and the visual effect desired to be created by the lighting would decide the type of lighting for the landscape[1]. Low wattage halogen incandescent and compact fluorescent lamps (CFLs) are the two most commonly used light sources in this application. The appearance of the landscape and the building varies significantly depending on the spectral power distribution (SPD) of the light source used. The SPD imparts certain color appearance to the light and the lighted environment; for example, a halogen source will cast a slightly yellowish tone, whereas the compact fluorescent lamp will cast a whitish tone. In addition, the appearance of the object colors could look significantly different depending on the source SPD. In addition to their differences in color properties, both these light sources have other characteristics that differ. In general halogen incandescent lamps have lower luminous efficacy and shorter lamp life compared to CFL lamps, while halogen incandescent lamps offer greater flexibility to lighting specifiers since they come in a variety of wattages, beam shapes, and color temperatures. LED is a potential new light source for this target lighting application.

White light LEDs were first developed in the mid 1990s [2]. Since then their development has been very rapid. Some of the white LEDs presently available in the market have a luminous efficacy of the order of 24 lumens per watt, which is greater than the luminous efficacy of halogen incandescent sources [3]. Being a low voltage and small package light source, LED is a good candidate for outdoor landscape lighting applications. The life of white light LEDs are being projected to 25000 hours with 70% lumen maintenance [4]. Being rugged, durable, and having a long lifetime makes the

LED even more attractive for this target application. White light from LEDs can be created in several ways. The two most common techniques presently employed are the excitation of a down conversion phosphor with the blue light emitted by a semi conductor, and the mixing of multiple colored LEDs, such as red, green, and blue (RGB), in appropriate proportions. Each of these techniques has advantages and disadvantages. The phosphor approach provides a single integrated LED package, whereas the RGB approach requires some form of external mixing element to get good quality white light. However, the RGB LEDs provides a more efficacious lighting system and higher lumens per watt as compared to the phosphor method, because the down conversion method involves losses. Furthermore, they have significantly different spectral power distributions (SPD) that will result in making the lighted space appear different. In this study both types of white LEDs and halogen light source were evaluated in an outdoor landscape setting to understand people's preference for these different light sources.

EXPERIMENT

A laboratory human factors experiment was conducted to investigate the acceptability of LED light sources for outdoor landscape lighting applications [5]. Prior to starting the experiment, a field survey was conducted to study the lighting designs commonly used and to measure light levels in these applications. Typical restaurants were targeted in the survey and it was observed that the most common source of illumination was incandescent or halogen for general lighting of the interiors and for exterior landscape. Based on this survey a scaled model (see figure 1) was designed with symmetrical scenes on either side to allow a side-by-side comparative evaluation of lighting. A typical façade for an upscale suburban restaurant was designed with a front approach and a garden. The model was built such that the color scheme used in the exterior setting could be changed easily.

The lighting fixtures used in this setup accommodated all three types of light sources: halogen, RGB LEDs, and phosphor white LEDs. Figure 2 shows the lighting fixture without the hemispherical reflector. An array of surface mount LEDs was arranged symmetrically around the center of the light fixture. The array consisted of individual red, green, blue, and phosphor white LEDs. Since the lighting fixtures were too small to house halogen light sources, optical fibers from a halogen-based fiber-optic lighting system were fixed in the central cavity of the fixture. A hemispherical cap, painted white inside, served as a mixer and a reflector to distribute the light. The red, green and blue light from the LEDs mixed and reflected from the hemisphere onto the surface of the model as white light. All of the light sources were connected to a control box with six switches, three for each side. This allowed the experimenter to control the lights on both sides of the setup during the experiment.

In this study four different light sources were evaluated: halogen, phosphor white LED, and two RGB LEDs. The characteristics of all four light sources are listed in table 1. The light output of each fixture was carefully adjusted such that all of them had similar light output and the light levels on the surfaces matched the values measured during the field survey. The porch area of the restaurant was lighted by low voltage incandescent sources.

The experiment was conducted with two different scenes, achromatic and chromatic. The achromatic scene had a gray pathway, gray stairs, white flowers, and gray area surrounding the flowers. The chromatic scene had a green lawn, and colorful flowers (light and dark shades of pinkish red and yellow). The pathway and the stairs were gray, similar to the achromatic scene. The illuminance values at the ground level were between 25 to 35 lux, similar to the light levels measured during the field survey, and were in the range recommended by the Illumination Engineering Society of North America (IESNA) handbook for outdoor pathway illumination, 20 – 40 lux [6]. Both sides of the model had very similar light levels and beam distributions.

In all experiments the light fixtures and their positions were unchanged, but the scene was changed between achromatic and chromatic. All four light sources were evaluated with both scenes. Initially the subjects viewed the lighting conditions side by side and rated their preference on a –3 to +3 scale, where –3 represented strong preference for the scene on the left and +3 represented strong preference for the scene on the right. Zero meant that the preference was equal for both scenes. Then they viewed each lighting condition by itself and rated their preference. Once again the rating scale was –3 to +3, however now –3 meant strongly disliked and +3 meant strongly liked. Zero meant neutral or no preference. The sequence of presentation of the achromatic or chromatic scene, comparisons, and ratings for individual assessment were randomized to minimize learning effects that could bias the results in a certain way.

Prior to starting the experiment all subjects were screened for color vision deficiencies. The subjects sat on a chair placed 76 mm (2.5 feet) away from the front edge of the model. On average the eye height of the subjects was maintained approximately20 mm (8 inches) above the ground level of the model. The setup was placed in a dark room with all room lights turned off. Subjects were given sufficient time to adapt to the light levels of the experimental scene. After an initial two-minute adaptation time, the subjects viewed two lighting conditions at a time and answered a series of questions comparing one scene to the other. Figure 3 shows the scenes during side-by-side assessment and individual assessment. The questions addressed the following subjective impressions for overall preference and individual component preference within side-by-side comparative ratings and individual ratings.

- Which side of the scene is more inviting?
- Which side does the lighting seem to be more appropriate for the landscape of this restaurant?
- Which side of the scene appears brighter?
- Which side of t he scene appears more colorful and vivid?

The same red, green and blue LEDs inside each light fixture were adjusted to provide either a 3050 K or a 5800 K white light. Due to the design of the setup the study had to be divided into two experiments. In the first experiment halogen, phosphor white, and RGB 3050 K systems were compared and rated by seventeen subjects. These included ten men and seven women, aged 20 to 55 years. Eight of the subjects had lighting knowledge. Almost half the number of subjects started the experiment with the achromatic scene; the remainder started with the chromatic scene. In the second experiment RGB 3050 K, phosphor white, and RGB 5800 K systems were compared and rated by eleven subjects. Five of the eleven subjects were common to both experiments. The subjects included five men and six women, aged 24 to 55 years. Seven of the eleven subjects had lighting knowledge. Similar to experiment 1, almost half of the subjects started the experiment with the achromatic scene; the remainder started with the chromatic scene. As shown in table 1, both RGB 3050K and the halogen sources had a correlated color temperature of 3050K, and both RGB 5800K and phosphor white had a correlated color temperature of 5800 K. Figure 4 illustrates the chromaticity values of the four light sources.

RESULTS

The first experiment in the comparative side-by-side evaluation tested the null condition where both scenes were illuminated by the same light source. As shown in figure 5, the average subject rating is around zero meaning equal preference for both sides. Statistical analysis showed that the ratings were not significantly different, which verified the null condition and showed that the scenes on both sides were very similar. Data analysis showed that the results of the side-by-side experiment highly correlated with the individual ratings[5]. Therefore in this manuscript only the results of individual ratings are presented.

The mean rating values for all of the experiments are summarized in figures 6(a), 6(b), 7(a), and 7(b). Variability within the ratings for all assessment scales ranged from $\pm$ 0.5 to $\pm$ 2.0. Statistical analysis showed that, for both scenes, chromatic and achromatic, the subject ratings for ‘like’, ‘inviting’ and ‘appropriateness of lighting’ was the highest for RGB 3050K ($p<0.05$), followed by halogen, and the lowest for the phosphor white LED light source. For the same questions in the second experiment, once again RGB 3050K was rated the highest ($p<0.05$) followed by RGB 5800K and phosphor white LED. However the difference between RGB 5800K and phosphor white LED was not statistically significant.

For the assessment of brightness in the chromatic scene in both experiments, the average individual ratings showed that the white phosphor LED was perceived to be the brightest ($p<0.05$). The difference between the ratings for brightness perception for all of the other light sources was not statistically significant. The achromatic scene was perceived to be the brightest when illuminated by the phosphor white LED in the first experiment. The difference for the ratings was not statistically different for RGB 3050K and halogen light source. However, in the second experiment the difference in brightness perception for all three light sources (Phosphor white LED and both the RGB LEDs) was not found to be statistically significant using the same p value.

In the first experiment the highest rating for the most colorful scene was for RGB 3050K ($p<0.05$). The second experiment also showed that the subjects perceived the scene to be most colorful when the scenes were illuminated by the RGB systems. The scene was perceived to be equally colorful under RGB 5800K and RGB 3050K and the ratings for these light sources were not statistically different from each other. The lowest rating for the scene was when it was illuminated by the phosphor white LED. The achromatic scene was perceived to be the least colorful when illuminated by the phosphor white LED. The difference in the ratings was significantly different from the RGB systems and halogen light source ($p<0.05$). The difference in ratings for colorfulness for RGB systems and halogen was not statistically significant ($p<0.25$) when the scene was achromatic.

DISCUSSION

The goal of this study was to show how the subjective impressions for overall and individual components change from one light source to another for a commercial outdoor lighting application. Overall the RGB LEDs performed equal to or better than the most widely used halogen light source in this given setting. People's expectations of perceived brightness levels differ from one application to another. In general light sources with higher CCT enhanced the perceived brightness of the space. In this setting people preferred slightly dim light levels. Although some of the subjects preferred the brighter light for the approach pathway since they felt the approach area appeared clearer and would be safer climbing steps, a majority of the subjects found the phosphor white to be too bright, even for the approach. Overall, the halogen and the RGB LEDs were preferred since the slightly dimmer ambience was more typical of restaurants, and the subjects found it more inviting.

The lighting industry typically uses color rendering index (CRI) as the metric to evaluate color rendering properties of a light source. Even though CRI may not be valid at low light levels, the lighting specifiers generally want a high CRI lamp for outdoor landscape lighting applications. This metric has many drawbacks and a recent paper showed that CRI is not a good metric for measuring color rendering properties of light sources and people's preference of colors [7]. This study also demonstrated that subject ratings for colorfulness of a scene were highest for RGB type LEDs that had the lowest CRI values.

Being a small, low voltage, rugged, durable, and long life light source makes LED a very attractive candidate for outdoor landscape light applications. Presently, the LEDs are more efficacious than halogen light sources, which are most widely used in this application. The authors of this manuscript feel that a field study would be greatly beneficial for further validating the results found in this laboratory study and for quantifying their energy use. In a field study one can expect spill light from adjoining parking lots or streetlights to enter the space. Usually, the light sources used in parking lots and streetlights are high-pressure sodium, low-pressure sodium, metal halide, or mercury vapor lamps. These light sources have significantly different spectral power distributions. It would be interesting to see in a field study how this spill light interacts with the outdoor landscape lighting and affects people's perceptions.

Since LEDs are still under development they are more costly than traditional halogen sources at the present time. However, we can expect them to become cost competitive in the near future since they are advancing very rapidly.

ACKNOWLEDGEMENTS

The authors thank Color Kinetics, Inc. for the sponsorship of the project; Lighting Research Center (LRC), Troy, NY, for the use of the facility resources for the experiment; Schott Fibers, for the donation of fiber optic equipment; and Rich Pysar, Dave Cyr, Lei Deng and Martin Overington of the LRC for their technical assistance.

REFERENCES

1. *J. Moyer,* The Landscape Lighting Book, *J. Wiley and Sons, Inc. 1992.*

2. *S. Nakamura, T. Mukai, M. Senoh,* "Candela-class high brightness InGaN/AlGaN double-hetero structure blue-light-emitting-diodes," Appl. Phys. Lett. 64, 1994.
3. *www.lumileds.com, "Lumileds' Luxeon LED lamps retain 90%+ of light output for 9000 hours"(http:/www.lumileds.com/newsandevents/articles/lightingonline_0602pdf.pdf , Accessed on 07/17/02)*
4. *Nadarajah Narendran and Lei Deng,* "Performance characteristics of light emitting diodes", Proceeding IESNA 2002.
5. *I. Shakir,* "Evaluation of White LEDs for outdoor landscape lighting applications", Thesis, M.S in Lighting, RPI, 2003.
6. *Dr. M. Rea, Editor in Chief,* "The IESNA Lighting Handbook", *Ninth Edition.*
7. *Nadarajah Narendran and Lei Deng,* "Color rendering properties of LED light sources," SPIE Proceedings, Vol. 4776, 2002

* Insiya Shakir, email- shakii@rpi.edu @rpi.edu, ph 518-687-7100

Figure 1: The set up of the landscape scene

Figure 2: A typical light fixture used in the experiment. The fixture used an array of red, green, blue and phosphor white LEDs arranged symmetrically and five fibers from a halogen light source were sealed in the center.

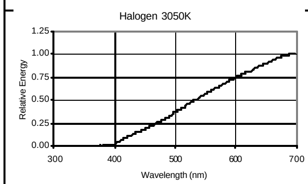
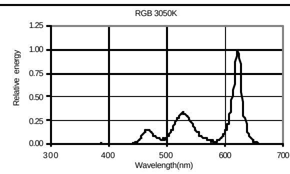
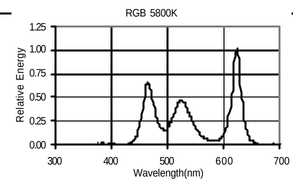
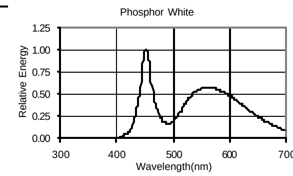
Halogen	RGB 3050K	RGB 5800K	Phosphor White
1 . Spectral Power Distribution			
			
2 . Correlated Color Temperature (K)			
3050	3050	5800	5800
3. Color Rendering Index			
97	46	48	80
4. CIE x, y Chromaticity Coordinates			
0.4427, 0.4163	0.4404, 0.4104	0.3270, 0.3270	0.3294. 0.3345

Table 1: Characteristics of light sources used in both the experiments.

Figure 3: The illuminated scenes for side -by-side comparative ratings and individual ratings

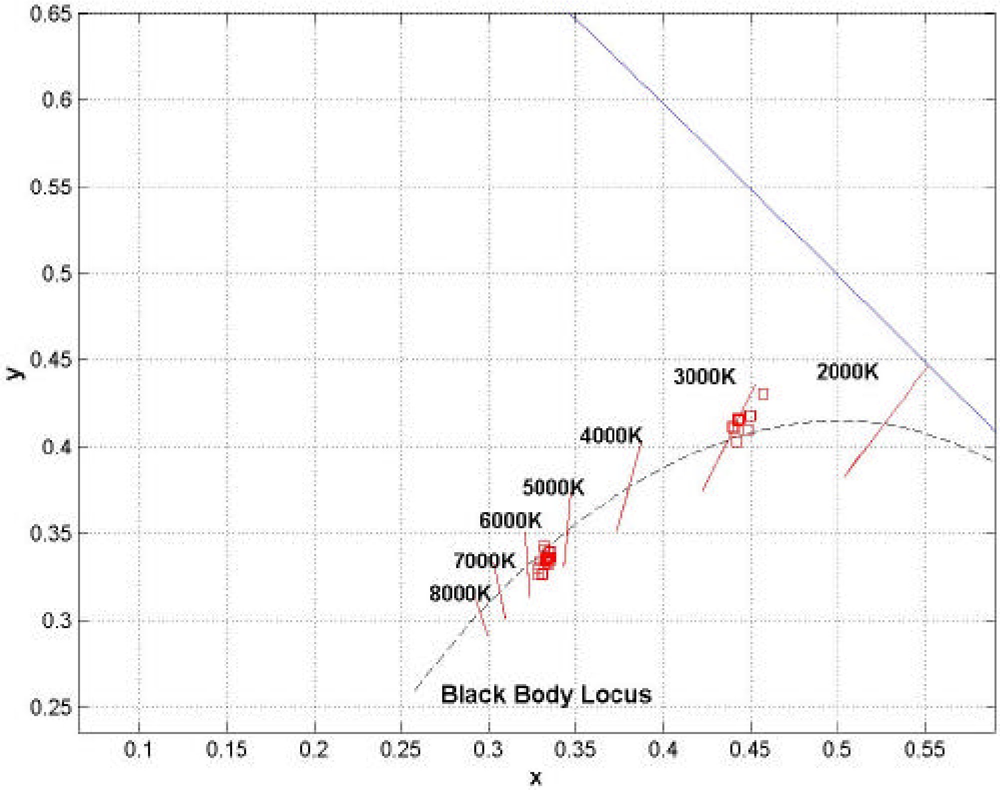


Figure 4: 1931 CIE diagram with x, y, chromaticity coordinates of the 4 light sources; Halogen 3050K, RGB 3050K, RGB 5800K and phosphor white LED 5800K.

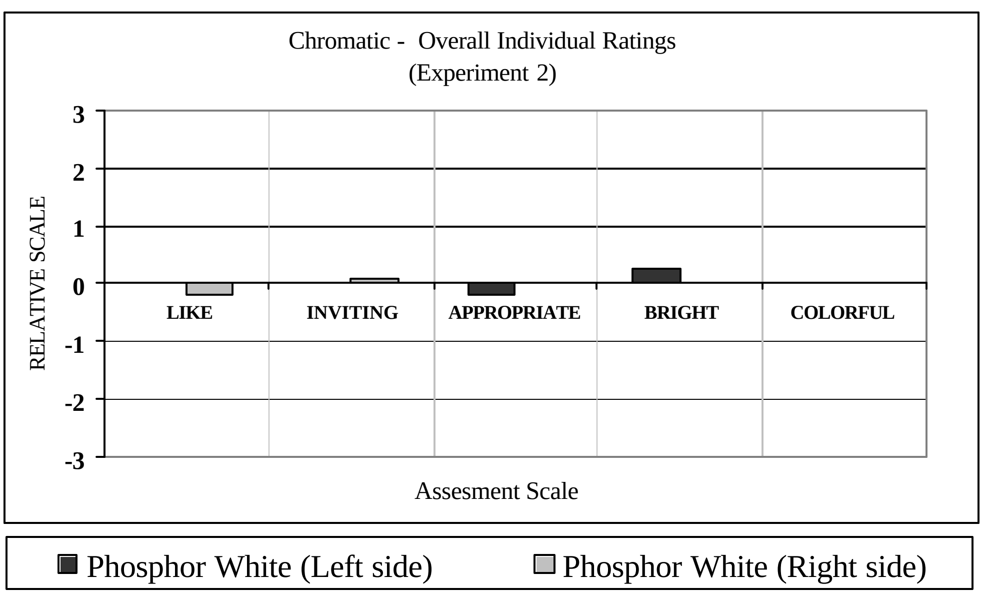


Figure 5: Null Test results for the second experiment showing preference for one light source over another for the same condition. Both sides had the phosphor white LEDs switched on. The ratings were very close to zero, indicating that the two sides were identical.

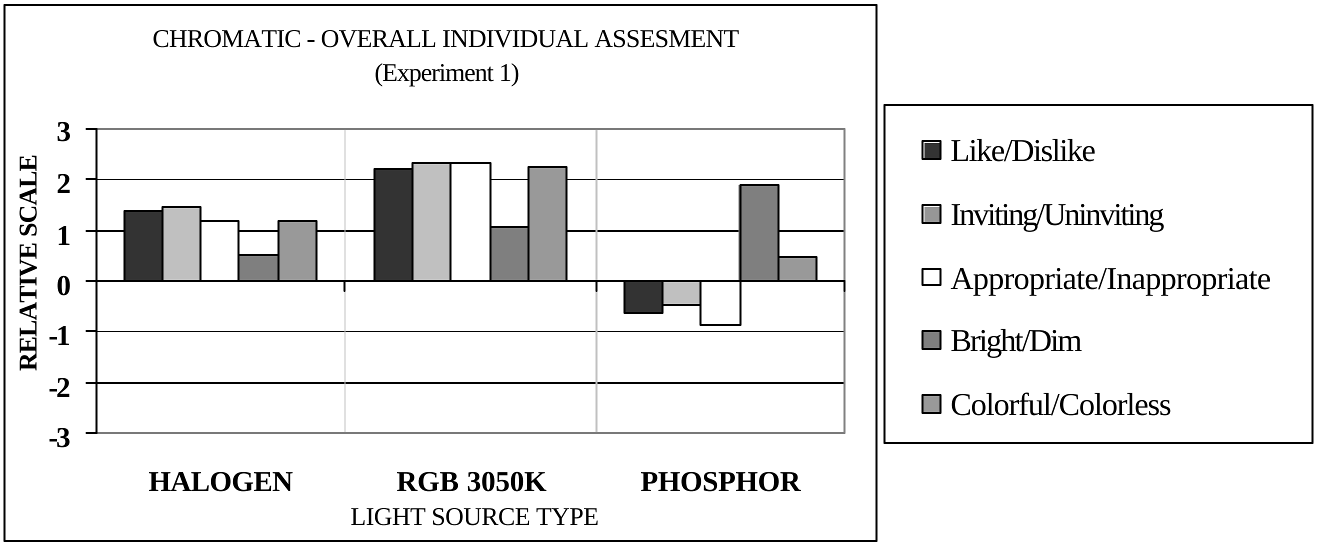


Figure 6a: The results for the chromatic scene for the experiment no. 1. The first experiment used halogen, RGB 3050K and phosphor white 5800K as light sources.

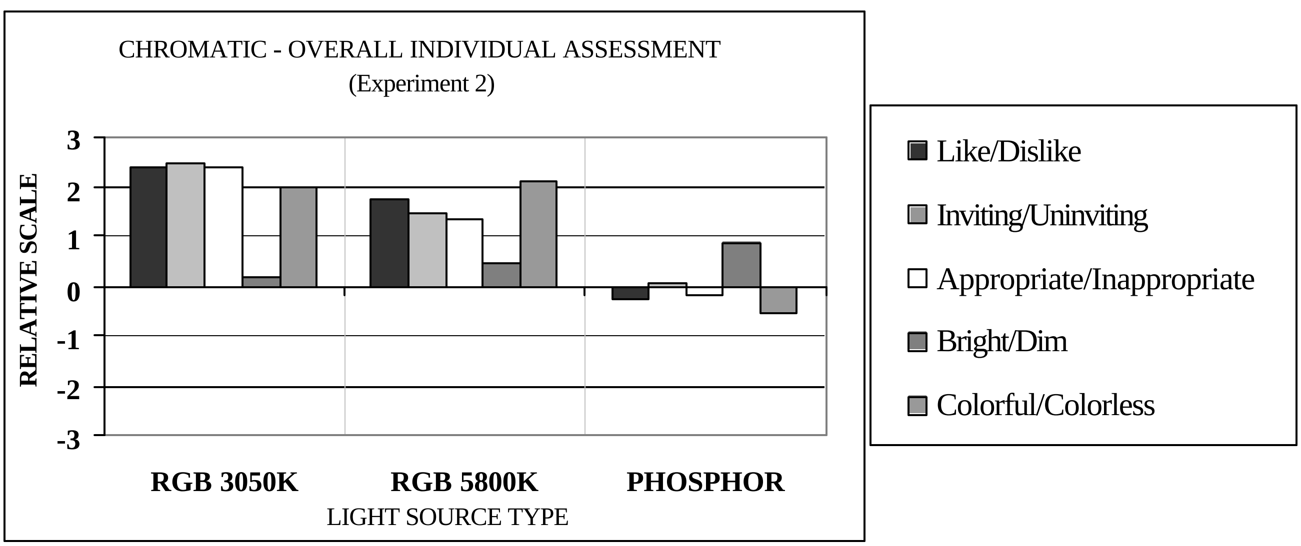


Figure 6b: The results for the chromatic scene for the experiment no. 2. The second experiment used RGB 3050K, RGB 5800K and phosphor white 5800K.

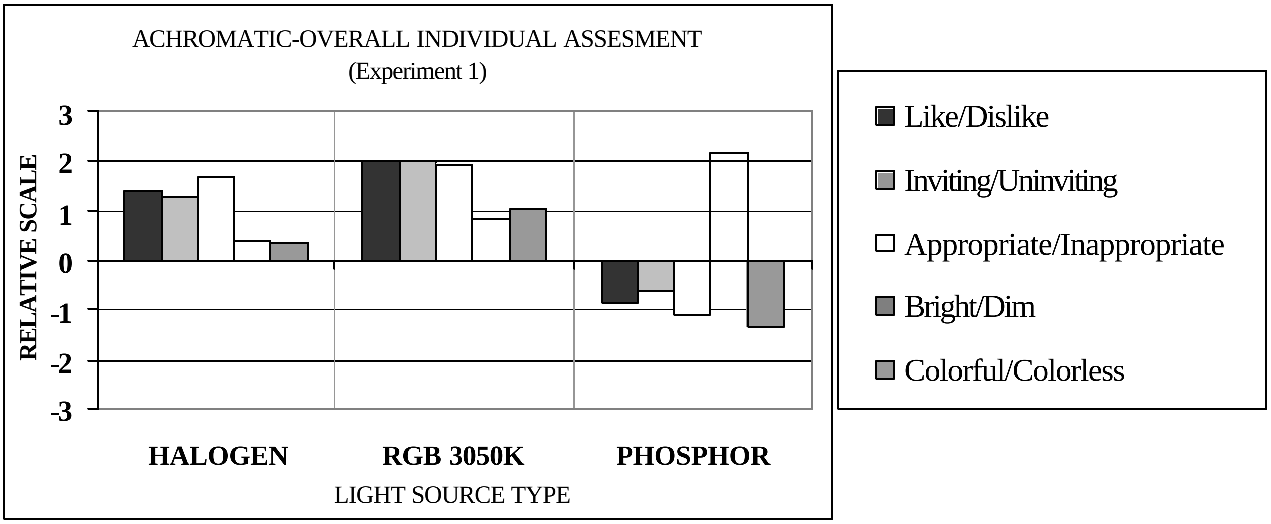


Figure 7a: The results for the achromatic scene for experiment no. 1. The first experiment used halogen, RGB 3050K and phosphor white 5800K as light sources.

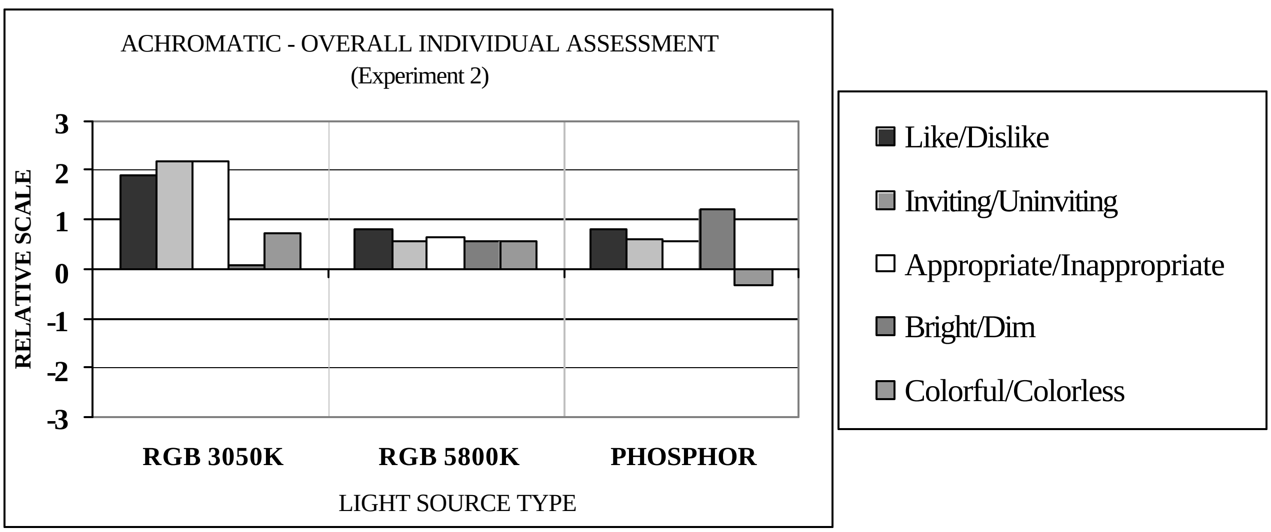


Figure 7b: The results for the achromatic scene for experiment no. 2. The second experiment used RGB 3050K, RGB 5800K and phosphor white 5800K.