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COLORED LIGHT APPLICATION IN A RETAIL DISPLAY WINDOW

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ABSTRACT

A retail display window is typically designed to attract potential customers. In a shopping mall, display windows compete with one another to capture the attention of shoppers by using high light levels. Furthermore, it is typical to see high illuminance ratios in the range of 15:1 to 30:1 between the display object and the background. A majority of retailers use halogen PAR or MR lamps in their display windows. The direct impact of retailers increasing the overall light levels and using relatively inefficient halogen PAR and MR lamps in these applications is increased energy use. The shortage and rising cost of energy in the United States has triggered many local governments to implement energy conservation programs. Identifying alternate lighting solutions that can result in lower energy consumption was one motivation for this study.

A laboratory experiment was conducted to investigate the usefulness of colored LEDs in retail display window applications. The intent in this study was not to change the traditional white accent light to a colored light but to use colored light on the background of the display window. Human subjects viewed two side-by-side, identical mock-up display windows, one with a colored background and the other with a white background, and rated their preference. Subjects showed strong preference for the colored background, compared to the white background. Furthermore, the use of colored light on the background allowed the accent light to be decreased without sacrificing visual appeal, ability to capture attention, and ability to see displayed objects clearly. It appears from this initial laboratory study that the amount of accent light can be reduced up to fifty percent, which could provide energy savings.

INTRODUCTION

It is common to see in shopping malls today, retail display windows competing with one another to attract customers' attention. A well-designed display window has several functions, including capturing the attention of potential customers, providing visual appeal, and conveying a message regarding the merchandise sold in the store. The authors of this manuscript surveyed 15 display windows in a 1.6 million square foot shopping mall in Albany, New York, and found that stores in general, use high light levels especially in display windows. It also became evident that tungsten halogen and incandescent reflector lamps are still the most widely used light sources in display windows. The reason for the wide use of these light sources is that they provide the greatest flexibility to lighting specifiers in terms of fixture size, wattage, beam spread, and intensity control. Furthermore, these light sources have very good color rendering properties, an important factor for lighting display windows. However, the tungsten halogen and incandescent reflector lamps suffer from one major shortcoming, they have low luminous efficacy. A typical retail display window of 10 linear feet frontage could use up to twenty MR-16 lamps or ten PAR lamps each in the range 50 to 75 watts. Therefore, the current display lighting practice leads to significant energy use.

Recent trend for themed scene displays in the retail environment has led to the use of colored lights in display windows. Color filtering of the incandescent light sources is extremely inefficient. The color filtering of fluorescent light sources is both economical and efficient. However, the newly developed lighting technology of light emitting diodes (LEDs), presents a better package of benefits for display lighting applications. LEDs produce colored light efficiently. In addition, LEDs can be easily controlled to provide multiple color and intensity. The goal of the experimental study detailed in this manuscript was to investigate the applicability of colored lights to retail display windows and quantify their performance (Simeonova, 2001).

There are several publications that have shown that high light levels can improve attention capture (Flynn, et al, 1973; Boyce, 1981; Rea, 2000; Wyszecki and Stiles, 1982). In display lighting applications it is typical to see high illuminance ratios in the range of 15:1 to 30:1 between the display object and the background [Philips, 1991A]. The *Illumination Engineering Society of North America (IESNA) Handbook* also recommends more than 3000lx for horizontal illuminance and up to 500lx for vertical illuminance for retail display windows (Rea, 2000). Conversely, there are other studies that have shown that other factors such as color and spatial and temporal variation of brightness can increase attention capture (Chaparro, et al, 1993; Turatto and Galfano, 2000; Irwin, et al, 2000; Nothdurft, 2000). Likewise, there are several publications that have shown that color increases visual appeal and in certain applications it is more preferred than white (Birren, 1971, Wong, 1994).

Although there are many research studies that have addressed the issue of luminance and color for attention capture and visual appeal, there are no studies that have systematically explored the use of colored light in retail display windows, and have quantified their performance. Therefore, a laboratory experiment was conducted to investigate the applicability of colored light to retail display windows and to quantify its performance in terms of attention capture, visual appeal, and energy use, compared to traditional display window lighting (Simeonova, 2001).

It is worth mentioning here that there are special requirements for the lighting of display objects (Philips, 1991B). Color temperature (warm or cool), light levels and color rendering index (CRI) are all important parameters when lighting a display window. Usually, a very good color rendering (>85 CRI) light source is recommended to provide for natural appearance of the display objects. Therefore, the intent in this study was not to change the traditional white accent light to a colored light but to use colored light on the background of the display window.

EXPERIMENT

Two human subject experiments were conducted in the laboratory.

- The objective of experiment 1 was to determine if colored light on the background of a display window, whether static or modulated, is more visually appealing and able to capture attention more than white light on the background.
- The objective of experiment 2 was to determine if using static colored light rather than white light on the background would allow for the decrease in accent light without sacrificing visual appeal, ability to capture attention, and ability to see display objects clearly.

Prior to building the experimental setup, the authors conducted a survey of 15 display windows in Crossgates shopping mall, Albany, New York. Incandescent halogen PAR and MR lamps were the most widely used luminaires in these applications. Usually, the PAR fixtures were ceiling-recessed and provided grazing light on the background of the display window, while the MR fixtures were track-mounted and located at the front edge of the window and provided directional accent light. Table 1 shows the ranges of illuminance and luminance values, measured inside the display window and in the surrounding area. On an average, the luminance ratios between the display object and the background were in the range 12:1 to 25:1. It is worth noting here that several display windows did not have a back wall instead they were open to the store inside.

	Illuminance (lux)	Luminance (cd/m²)
Surrounding Area	80 - 120 horizontal at floor level	
Display	2200 - 3700 vertical	800 - 1500
Background	250 - 500 vertical	50 - 70

Table 1: Summary of field measurements

Experimental Setup

The experimental setup used in this study is shown in Figure 1. Two scaled-down display windows were built and were placed side-by-side for comparative viewing.

Display Window

The dimensions of the display window were based on the size of the laboratory space available and the viewing field typically subtended by display windows in a realistic setting. The opening of the mockup display windows measured 3-feet by 3-feet. The two display windows were viewed from a distance of 7 feet. White foam sheets, matte finish with a reflectance of approximately 98% provided the neutral background for the displays. The sides and the platform of the windows were covered with black foam to conceal metal frame and to absorb any spill light. The ceiling area within the display window was open to allow the ceiling-mounted lighting fixtures to light the display objects. The platform for the display was at 46-inches above floor level and it was intended for standing viewing position at 7 feet distance from the display window.

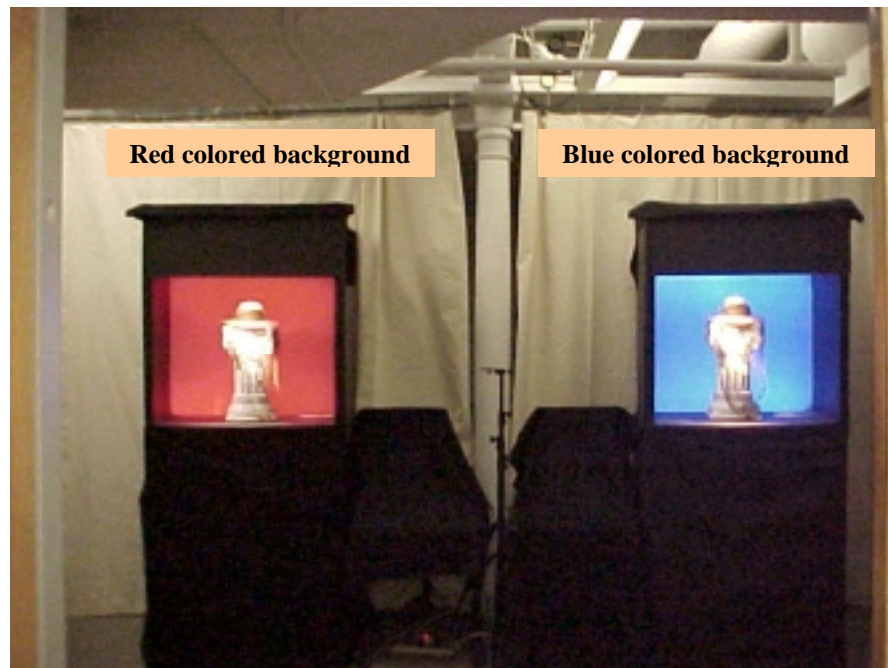


Figure 1: Experimental setup, composed of two side-by-side display windows

Lighting

Two six-inch wide lighting covers were created in front of the back wall, at the top and at the bottom, to house linear arrays of colored LEDs. The linear LED arrays spanned the entire width of the display window at the top and at the bottom. Two 75-watt, 120-volt incandescent PAR30 lamps were placed in the lower covers to light up the background of the display. This setup allowed the background to be lighted either by the halogen or LEDs. The displays in the scene were accent-lighted by two 50 watt 12 volt MR16 (7 degree, narrow spot) lamps. There was no daylight in the space. The ambient light was provided by indirect fluorescent luminaires. The average ambient illuminance at floor level was 10fc. The room ceiling height at the viewing position was 9 feet.

The colors chosen for lighting the back wall for this study were red and blue (the two extremes of the visual spectrum). The dominant wavelength of the red and blue LEDs was 640nm and 470nm respectively. Table 2 illustrates the measured light levels inside the mock-up display windows for the different lighting scenes.

	Illuminance (vertical lux)			Luminance (cd/m ² at 100%) Experiments 1 and 2		
	White	Red	Blue	White	Red	Blue
Display	5000max 3000aver	-	-	1200 max	-	-
Background						
Experiment 1	250	70	40	70	7	7
Experiment 2	250	70	40	70	10	7
Passageway	100	Light levels kept similar to field measured values				
Horizontal illuminance						

Table 2: Measured light levels inside the display windows

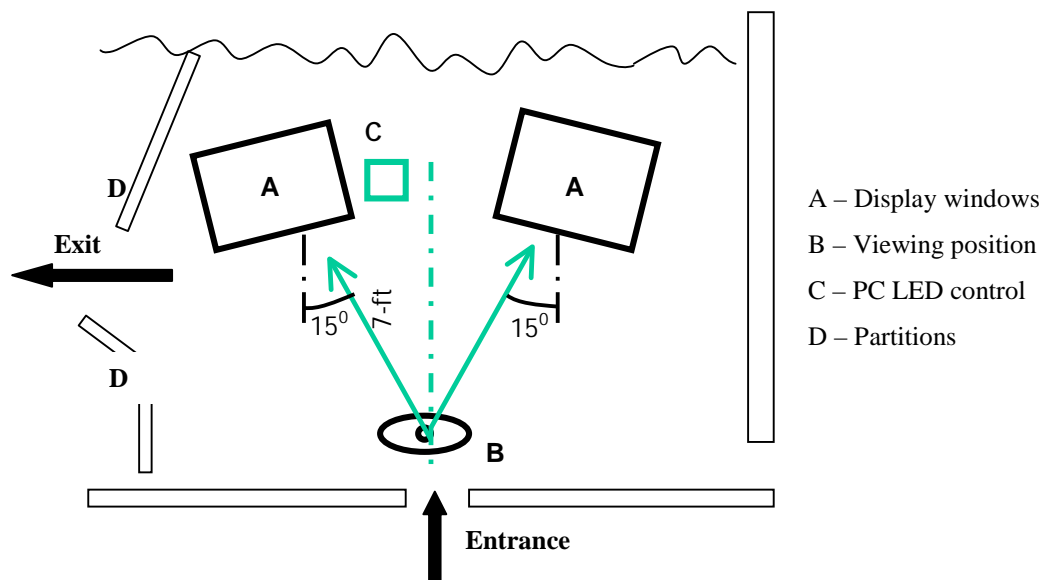


Figure 2: Arrangement of experimental setup

Display Objects

Both display windows carried identical display objects in experiments 1 and 2. The display consisted of achromatic objects such as a straw hat, fish net, and seashells, all in earth-and sand-toned colors, placed over a white pedestal, that was located in the center of the window.

Human Subjects

Nine subjects participated in experiment 1 and seventeen subjects participated in experiment 2. Their ages ranged from 25 to 58 years old. All of the subjects were screened for color vision deficiency. The majority of the subjects (over 90%) had no formal lighting education and the rest had some knowledge about lighting.

EXPERIMENT 1

The objective of Experiment 1 was to determine if colored light on the display window background, static or modulated, has the capability to provide higher visual appeal and can capture attention more than the white light display. Figure 2 illustrates the experimental arrangement. Nine subjects took part in Experiment 1. All human subjects entered the experiment area through a doorway and viewed the two display windows simultaneously. One of the windows had colored light in the background while the other had white light. Both windows had identical white accent light. The subjects answered a continuous nine-step rating scale, where subjects could record the magnitude of their preference. Figure 3 shows a sample continuous nine-step rating scale.

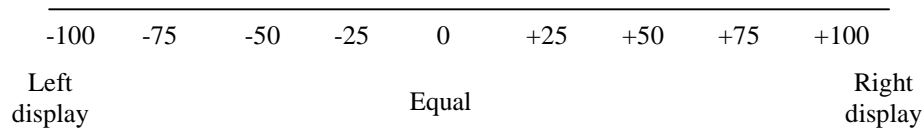


Figure 3: Continuous nine-step preference rating scale

While the subject answered the questions the experimenter changed the lighting condition. A total of five background lighting conditions were presented in this experiment: static white, static red, static blue, modulated red, and modulated blue. For each comparison pair the subject was given one minute to observe both display windows as presented. After that the subject exits the testing area and answers the questionnaire. Modulated refers to a slow sinusoidal variation (6 seconds per cycle) of luminance, from 100 % to 20%. The testing session for each subject lasted approximately 45 minutes with a 10-minute break to prevent fatigue. Altogether, ten comparison pairs were presented in random order to nine subjects in experiment 1. The ten comparison pairs are listed in Table 3.

Pair Number	Compared Lighting Conditions
1	Red static with Blue static
2	Red static with White static
3	Red modulated with Red static
4	Blue static with White static
5	Red modulated with Blue static
6	Blue modulated with Blue static
7	Red static with Blue modulated
8	Red modulated with Blue modulated
9	Red modulated with White static
10	Blue modulated with White static

Table 3: Comparison pairs for lighting scenes

Prior to beginning the experiment, both display windows were set to all white lighting condition. For this condition subject ratings showed that the two windows scored equal points, and therefore the null condition was verified.

The results of experiment 1 are shown in Table 4 and the numbers indicate the total mean preference rating score for each lighting condition. Only the absolute value of the ratings was counted. T-test statistical analysis was performed to compare the means for each lighting condition against all other lighting conditions.

Static and modulated blue lighting conditions, and modulated red lighting conditions scored high for attention capture while static red and white scored low for attention capture. Likewise, static and modulated blue scenes

provided the highest visual appeal. Both static and modulated red scenes scored less than white for visual appeal. Therefore, overall blue colored light performed better than white light for attention capture and visual appeal. Although, modulated red was able to capture attention more than white, all other red conditions were disliked. From this experiment it is difficult to conclude that colored light on the display window background has the capability to provide higher visual appeal and increase attention capture capabilities for all colors. It is possible that the results would be different for different colored light levels. The light levels on the colored background were set based on the highest available light from the blue LED array.

Lighting condition	Attention capture	Visual appeal
White static	14	18
Red static	12	15
Blue static	31	34
Red modulated	26	10
Blue modulated	47	39

Table 4: Results of Experiment 1. The numbers indicate the total mean preference rating score for each lighting condition.

In Experiment 1, the red and blue backgrounds were kept at equal luminance values, 7 cd/m^2 . It is known that for saturated colors equal luminance does not mean equal brightness. In fact, the red scene in experiment 1 looked less bright. It is shown later in Experiment 2 that when the brightness of the background was raised to match the blue condition, the ratings for static red increased much more than the white for attention capture and visual appeal.

EXPERIMENT 2

The objective of experiment 2 was to determine if static colored light on the background would allow for the decrease in accent light without sacrificing visual appeal, ability to capture attention, and ability to see displayed objects clearly. As in Experiment 1, both display windows were viewed side-by-side simultaneously. One of the display windows was kept as the control where the light on the background was white and the accent light was kept similar to the light level used in Experiment 1. This accent light level is denoted as 100% of accent light. The second display window was the test window, where the background light was static blue (7 cd/m^2), static red (10 cd/m^2), or static white (70 cd/m^2). One difference between Experiment 1 and 2 is the two colored windows in the second experiment had similar brightness instead of similar luminance. This was met when the blue window had 7 cd/m^2 and the red window had 10 cd/m^2 . In the test window the accent light was decreased from 100 % to 0% in seven steps (100%, 70%, 55%, 35%, 25%, 10%, 0%), using mesh filters that did not change the spectral power distribution of the accent lights. Three test sessions were conducted for the three different background colors. In each session, a total of seven comparison pairs were presented for preference rating to the participants, one pair for each one of the seven steps or levels of accent light.

Experiment 2 was very similar to Experiment 1 and the same experimental protocols were followed. A total of 17 subjects participated in three experimental sessions. Prior to the commencing the second experiment, subjects viewed the two windows, while they were both lighted identically with all white light. The results once again indicated that the two windows scored equal points, and the null condition was verified. Experiment 2 partially replicated Experiment 1 when the accent light was at 100% in both windows and the test windows had different colored background light. The results from this first step supported the previous findings of Experiment 1 for most part. Figure 4 shows these results. The vertical axis at 0 represents the neutral or non-preference condition. The area above the 0 (marked with positive numbers) represents the preferences for the test display window (colored or white) and area below the 0 (marked with negative numbers) represents the preference for the reference display window, with white light on the background and 100% of accent light

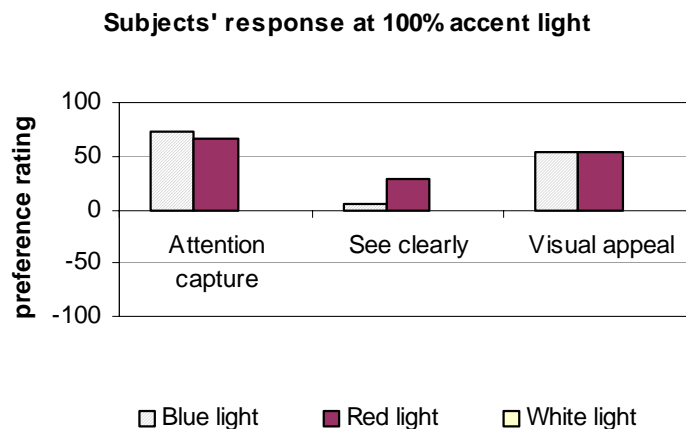


Figure 4: Experiment 2 preference rating at 100% accent light in both displays.

As mentioned earlier seventeen subjects took part in Experiment 2. The results for Experiment 2, the mean preference for each lighting condition for all indicators, are shown in Figure 5. The horizontal axis represents the amount of accent light. Once again the area above the 0 line on the vertical axis (marked with positive numbers) represents the preferences for the test display window. The area below the 0 lines on the vertical axis (marked with negative numbers) represents the preference for the reference display window.

Changing the light level for red to 10 cd/m² in Experiment 2 compared to 7 cd/m² in Experiment 1, changed the preference rating. As seen in Figures 4 and 5, at 100% accent light condition and at the selected background light levels, the static colored lights were much preferred for attention capturing and for visual appeal compared to the static white light. In all cases the subjects were able to see displayed objects clearly, indicated by near 0 answers in the last graph in Figure 5.

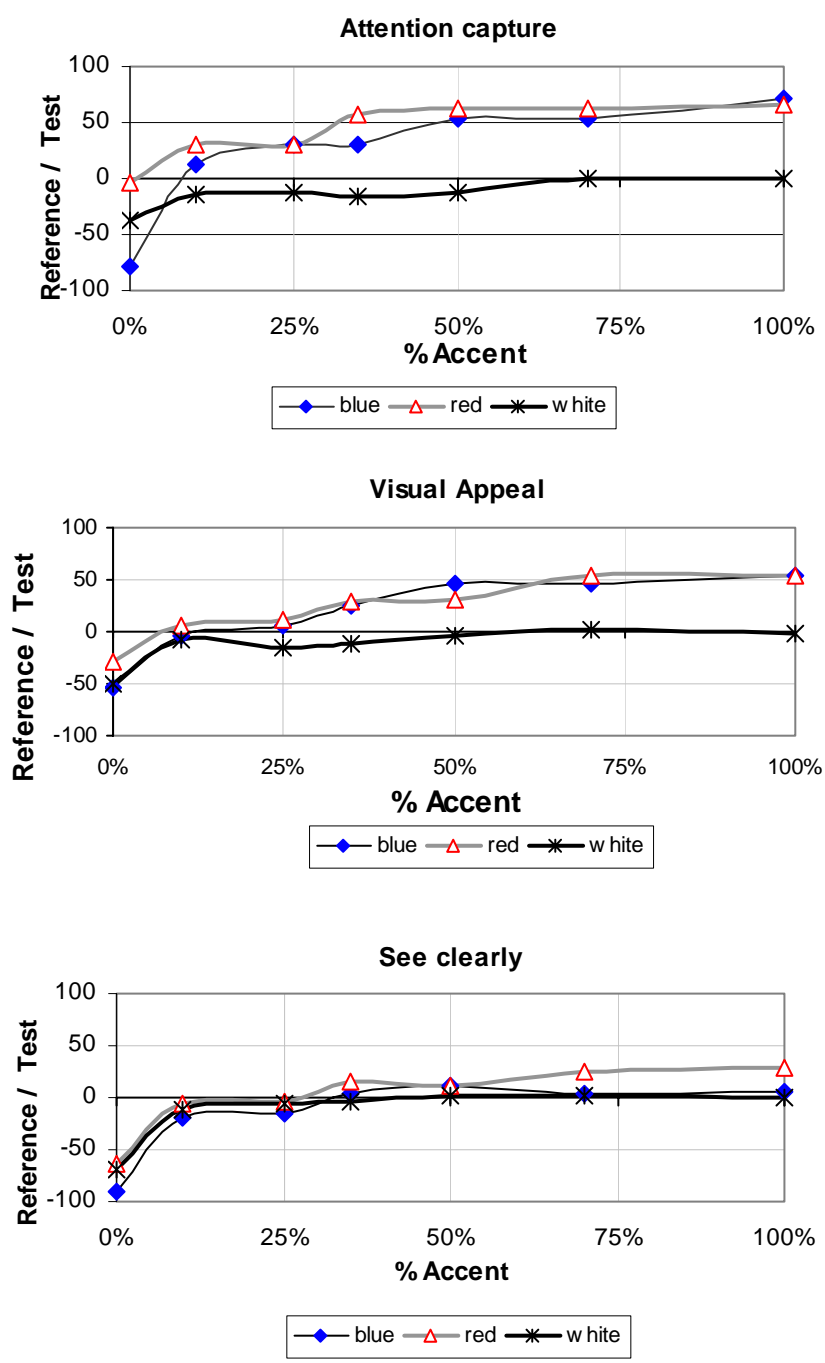


Figure 5: Mean preference rating for Experiment 2. On the vertical axis scores below 0 are for the reference display (white background with 100% accent light), and scores above 0 are for the test display (colored and white background with varying amounts of accent light).

Table 5 shows the average standard deviations for all subjects, for the indicators averaged over all 7 levels of accent light. As seen from Table 5, there was a great variability between the subjects in their subjective preference rating.

	Attention capture	See clearly	Visual appeal
Red	53	54	62
Blue	45	46	59
White	31	21	27

Table 5: The average standard deviations for all subjects, for the various indicators.

As illustrated in Figure 5, when colored light is used on the background, an elevated long flat plateau of higher preference is maintained until the accent light reaches approximately 50% of the original accent light value. The preference rating is high for *attention capture* and *visual appeal* for colored background, while for *see clearly* the colored background did not make much difference compared to the white light background condition. Below 50% accent light, the preference rating for the colored backgrounds, gradually decrease until approximately 10% accent light. It is at very low accent light levels (below 10%) a sudden sharp decrease is observed and the preference rating switches sides and goes towards the typical all white light display window. For white light background condition, no preference for either display windows is maintained until approximately 70% accent light. Below 70% accent light, the preference rating for the reference window, all white light with 100% accent light increases.

It appears that the two factors, color on the background and the amount of accent light act independently in the two regions of the graph. In the plateau area it appears that the color has the most effect, while the accent light has little effect for the subjects' preference. In the escarpment area on the left, where the sharp decrease in preference occurs, the opposite can be assumed to happen, that the color has little effect, but that the accent light becomes critical for visual clarity of the display object and therefore influences the subjects' response.

In this experimental setup, slightly higher illuminance levels were used to get similar luminance levels as in practice. The initial light level would influence the length of the plateau region of higher preference in the graphs. If a lower accent light was used at the beginning this plateau length will be shortened accordingly.

Statistical analysis was performed on the data to determine if colored background and the amount of accent light had any significant effect on subject rating. The results of statistical analysis showed that from 100% to 35% accent light, colored background has a significant effect on subjects' preference for all indicators. Percentage of accent light output has no significant effect on subjects' preference rating and there are no statistically significant interactions for all three cases. For accent light from 25% to 0%, the accent light has a significant effect on subjects' preference for all indicators. For attention capture, the color on the background has also a significant effect on subjects' preference rating, while for the other indicators, color on the background has no significant effect. No interaction between the two factors, color and percentage accent light output, was found for all cases.

DISCUSSION

An experimental study was conducted to investigate the usefulness of colored LEDs in retail display window applications in terms of energy savings, visual appeal, and attention capture capabilities.

The results from Experiments 1 showed that display windows with blue (static and modulated) light and red modulated light in the background enhanced attention capture compared to the traditional all white light

display window. Static blue light in the background significantly enhanced the visual appeal of the display window. In Experiment 2, red static light also became visually appealing when the background light level was increased. The modulated colored light, red or blue, did not show a significant effect on enhancing the visual appeal of a display window. The ability to see displayed objects was similar for both colored and white light background display windows.

Further, the results from Experiment 2 showed that when static colored light is used on the background of a display window, the amount of accent light can be significantly decreased without sacrificing the attention capture and visual appeal capabilities. Therefore the use of static colored light in a display window holds promise for energy savings.

As in any laboratory study this one too has some limitations: The display objects and the surrounding areas of the mockup display windows were neutral in color. Therefore the colored background could have added the dimension of interest. In an actual mall, the display windows can carry multicolored objects, and the adjacent windows can have colors in them as well. The results from this study are obtained for a particular distance and angle of view. However in a shopping mall, people can observe display windows from different angles, depending on where they move from and when they see the display window. The two extremes of the visual spectrum, red and blue, were used for the display background. It is reasonable to expect that other colored light, such as green, will be also high in preference rating compared to the white light background, although the amplitude of this preference may be different.

The results from experiment 2 were consistent and supported the results from experiment 1; hence the effect of colored light was demonstrated with two separate groups of subjects. However, a higher number of subjects would be more representative of the population. A field study in a shopping mall, with the variety of competing display windows, will define how robust this effect is.

The authors of this manuscript feel that a field study is necessary to validate the findings and to quantify the actual energy savings in a typical shopping mall display window. The authors are hopeful of being able to secure funding to conduct a field study.

The authors conducted a short follow-up study to investigate the colored display issue. In this study the neutral color display objects were replaced with colored magazines and other objects typically found in a bookstore display window. The results were very similar, subjects preferred colored background to white background, and also the amount of accent light can be reduced in the windows with colored background.

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