LED Channel Letter Lighting

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Disclaimer

ABBREVIATIONS AND ACRONYMS

AC	Alternating Current
CCD	Charge-Coupled Device
cd	Candelas
LCD	Liquid Crystal Display
LED	Light Emitting Diode
PQL	Power Quality Logger
SCE	Southern California Edison
SCLTC	Southern California Lighting Technology Center
W	Watts

FIGURES

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EXECUTIVE SUMMARY

TECHNOLOGY DESCRIPTION

Channel letter lighting is used in both interior and exterior sign identification and is typically used to display the name of a store or business. Neon has been the traditional light source for channel letter signs, but like LED EXIT signs, light emitting diode (LED) technology is emerging as another light source for the channel letter sign market. However, there are many mixed energy savings and brightness sufficiency claims for LED technology compared to neon.

FIGURE 1: LED CHANNEL LETTER SIGNS WITH ACRYLIC FACE ON THE "C" OF THE LED SIGN

LED technology has been used as an alternative to incandescent and fluorescent technology in exit sign lighting. It is currently being used in an increasing number of businesses as an alternative to traditional neon technology for open signs. The directional nature of a LED can potentially make it an ideal technology for channel letter signs, an application in which light is wanted on the face of the letter. Channel letter signs are usually illuminated with neon.

PROJECT OBJECTIVE

The objective of the project is to show the incremental energy savings and demand reduction of currently available LED channel letter signs over traditional neon channel letter signs. The project assesses and verifies energy savings and demand reductions by measuring the performance of the technologies in a controlled laboratory environment.

Photometric tests were performed to verify uncertainties associated with the LED technology, including the brightness, or luminance, of the LED compared to the neon channel letter. Luminance measurements relatively quantify the brightness of LED channel letter signs in comparison to that of neon signs.

TEST EQUIPMENT

All testing was conducted at Southern California Lighting Technology Center (SCLTC) in Irwindale, California. The sign used for all testing was a Southern California Edison sign displaying the acronym "SCE". For uniformity in all photometric tests, only the "S" was tested, while the "C" and "E" were covered with black stage curtains. For power testing, the entire sign was plugged in and measured.

SUMMARY OF RESULTS

LUMINANCE MEASUREMENTS

WHITE LIGHT SOURCE

On average, neon has three times the luminance of LED technology. The difference was the least for the white light source with the blue acrylic face, in which neon showed an average of 2.7 times the luminance of LED. Examining the individual products shows that some LEDs have luminance values approaching that of the least luminous neon product.

COLORED LIGHT SOURCE

In comparing the average luminance values for the red and orange light sources, the neon is only 1.2 and 1.5 times brighter than the LED technology, respectively. The yellow light source with yellow face showed the greatest disparity, with the neon having 5 times greater average luminance than the LED products. Blue and green neon was 3.1 and 4.9 times more luminous than the LED products. Doubling of the blue LED lights greatly increased the LED luminance.

CHROMATICITY COORDINATES

The chromaticity values (x and y coordinates) were averaged across seven points on the letter "S" for all products. In comparing white light sources with colored acrylic faces, the largest color difference is 0.030 units for the green face, with the average neon being slightly more pure green than the average LED. The smallest color hue difference is for red, with both technologies falling well within the range of pure red.

In comparing colored light sources with matching colored acrylic faces, the largest color hue difference is again for green, with a difference of 0.120 units. The smallest color hue difference is again for red (0.003 units), followed by blue (0.006 units).

DEMAND

Power measurements were taken on all the white light source products. The neon products are all larger demand consumers than the LED products, as shown in Figure 2. On average, the neon products consumed 68.1 watts, ranging from 44.3 watts to 102.23 watts. The LED products consumed, on average, 24.0 watts, nearly one third of the neon average. The LED products ranged from 13.9 watts to 42.0 watts.

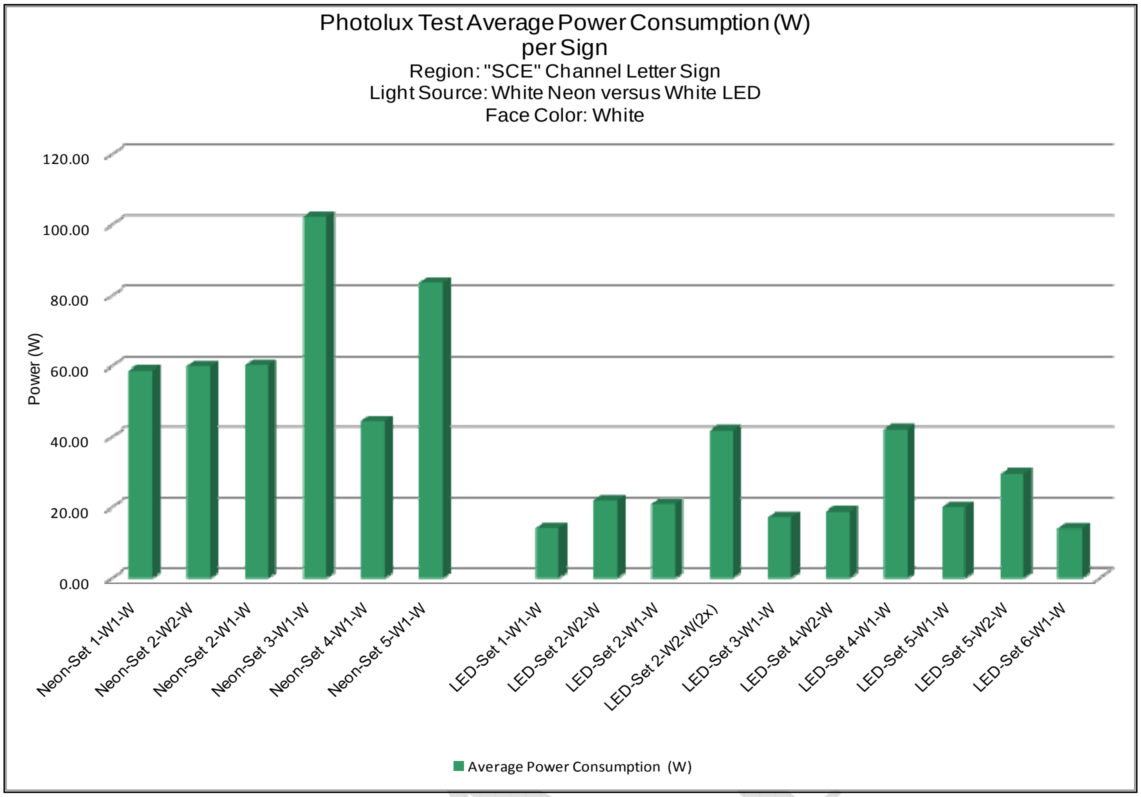

FIGURE 2: DEMAND OF INDIVIDUAL NEON AND LED WHITE LIGHT SOURCES

EFFICIENCY

One of the objectives of the channel letter tests was to determine if replacing neon with LED would result in energy savings without compromising sign quality. Luminance alone is not an adequate comparison without considering the energy consumption. Efficiency is measured in average luminance per Watt (cd/m^2/W), and allows an "apples to apples" comparison across the two product types.

WHITE LIGHT SOURCE WITH WHITE ACRYLIC FACE

Average luminance across seven spot measurements was used to determine efficiency. On average, the neon products are more efficient, with an average efficiency of 9.3 cd/m^2/W. The LEDs have an average efficiency of 6.6 cd/m^2/W. However, the best LEDs are more efficient than the worst neon lamps, as shown in Figure 3.

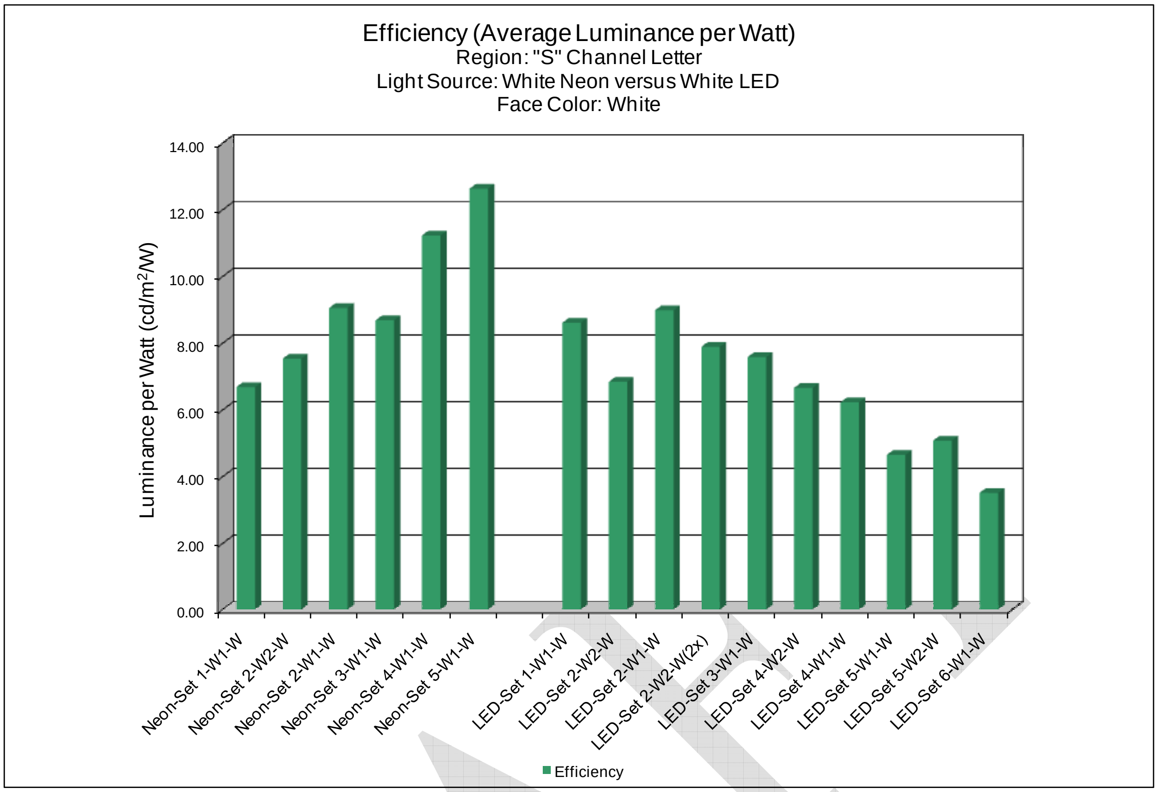

FIGURE 3: EFFICIENCY OF INDIVIDUAL NEON AND LED WHITE LIGHT SOURCES WITH WHITE ACRYLIC FACE

WHITE LIGHT SOURCE WITH COLORED ACRYLIC FACE

The white LED products are as efficient, on average, as the white neon products when covered with a colored acrylic face. Efficiency values of the LED products are only slightly lower than the neon products. The exception is the white colored face, in which the average LED product is nearly two points lower on the efficiency scale. Average efficiency values of the white light sources with colored acrylic faces are shown in Figure 4.

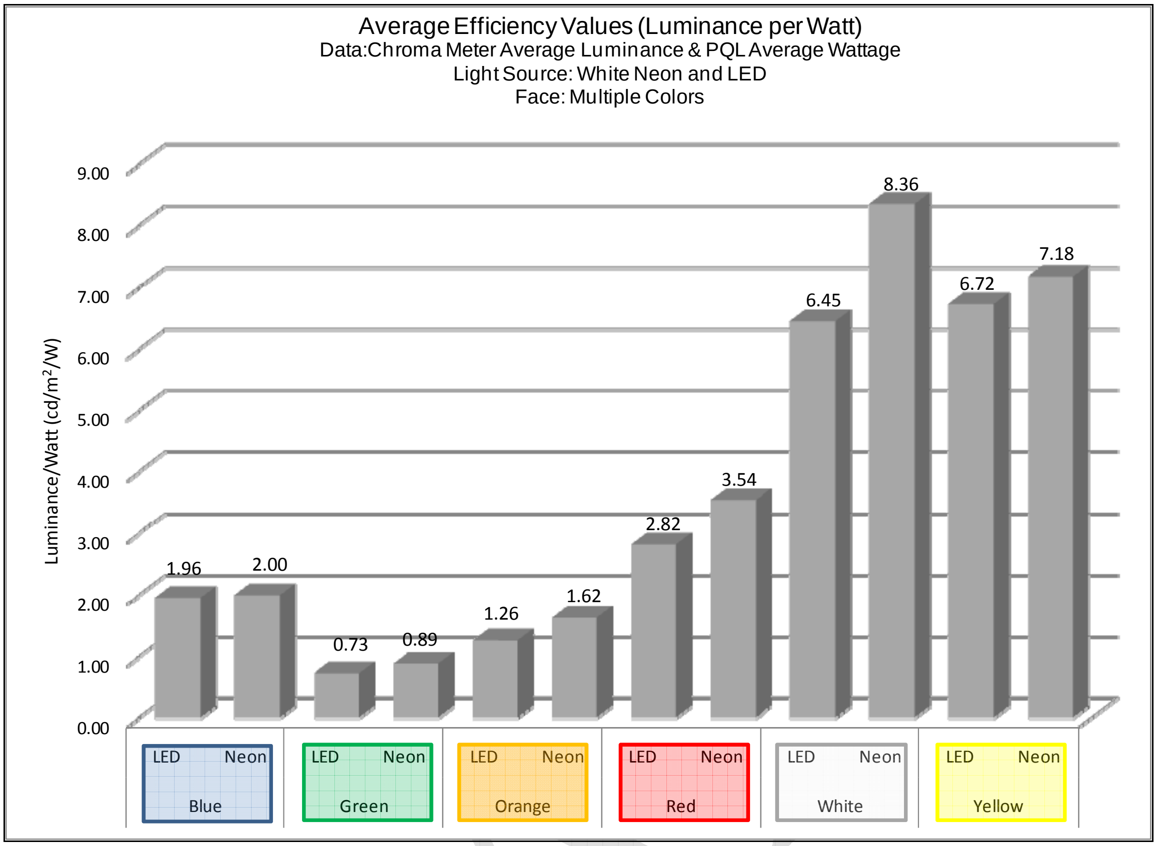

FIGURE 4: AVERAGE EFFICIENCY COMPARISON OF WHITE NEON AND WHITE LED WITH COLORED ACRYLIC FACE

Some individual white LED products with a colored acrylic face are more efficient than neon products. One green and one yellow LED product out-performed all neon products in efficiency.

COLORED LIGHT SOURCE WITH COLORED ACRYLIC FACE

When comparing the efficiency of the color light sources, the average efficiency values of the LED products are often comparable or better than the neon products. The blue, orange, and red LEDs are more efficient than the same color neon, with red being considerably more efficient. The green LED is only slightly less efficient than the green neon. However, the average yellow LED performed poorly with much lower efficiency than the yellow neon.

Average efficiency values of the colored light sources with matching colored acrylic faces are shown in Figure 5.

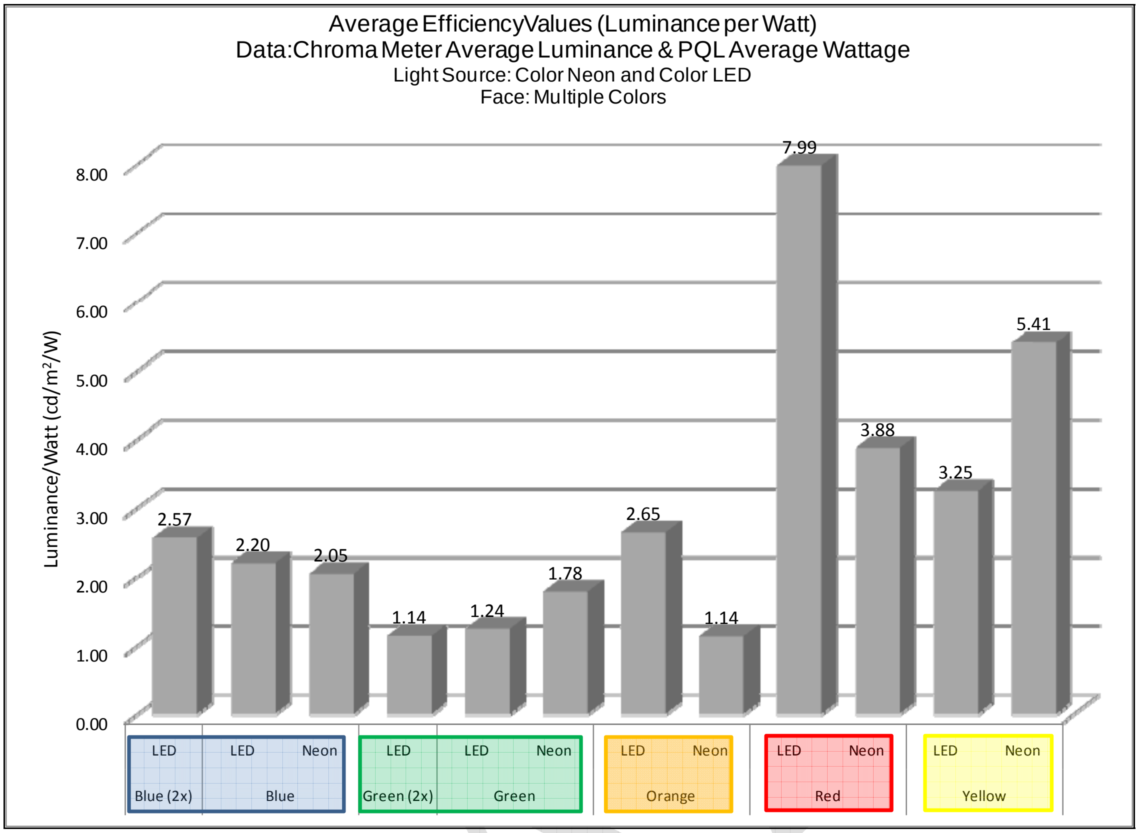

FIGURE 5: AVERAGE EFFICIENCY COMPARISON OF COLOR NEON AND COLOR LED WITH MATCHING COLOR FACE

When comparing individual products, some color LED products with a colored acrylic face are more efficient than neon. In all cases with the exception of yellow, one or more LED products are more efficient than the same color neon product. Three yellow LED products approach the efficiency of the one tested yellow neon product.

ENERGY SAVINGS

Energy savings analysis indicates that LED channel letter lighting can provide significant energy savings, notably in applications where it is used 24 hours per day.

TABLE 1: ENERGY SAVINGS SUMMARY FOR LED USE OVER NEON USE FOR 12 OR 24 HOURS/DAY

LED LIGHT SOURCE COLOR	ENERGY SAVINGS (KWH)- 12 HOURS/DAY	ENERGY SAVINGS (KWH)- 24 HOURS/DAY
Red	196.90	393.81
Orange	196.38	392.76
Yellow	165.70	331.40
Green	181.64	363.28
Green(2x)	153.31	306.62
Blue	178.79	357.58
Blue(2x)	136.43	272.87
White	210.21	420.42

COST

The California Sign Association and the International Sign Association performed a survey in partnership with SCE to determine the relative costs of producing LED versus neon channel letters. Results indicate, on average, the total cost of producing LED channel letters is greater than the cost to produce comparable neon letters. The relative production costs ranged from one manufacturer that claims LEDs are 15% less expensive to produce, up to another manufacturer that claims LEDs are 23% more expensive to produce.

CONCLUSIONS

LED technology for channel letter lighting is promising. Much advancement has been made in recent years with continued advancements still expected. The sample of products assessed here are a good snapshot of products available in 2007. LED technology uses significantly less energy than the traditional neon technology used in many channel letter signs. To maintain sign quality, especially sign brightness, these energy savings need to be considered in conjunction with the product efficiency. On average, LED technology tended to be less efficient when compared to neon, largely due to some products that had very low luminance. However, when looking at individual products, it was clear that some LED products are much better performers than others, and out-perform some of the neon products.

Another consideration when comparing LED to neon technology is the ease of purchase and installation. Neon channel letters must be hand formed to the channel, while LED channel letters come in flexible strips that do not need forming. This allows the user to manipulate the LED channel letter strips to create more luminance, if desired, by increasing the number of LEDs per letter. In these cases, one must weigh the energy consumption, luminance, and cost of the product to ensure it is still a cost-effective measure.

INTRODUCTION

TECHNOLOGY DESCRIPTION

Channel letter lighting is used in both interior and exterior sign identification and is typically used to display the name of a store or business. Channel letter signs are individually internally illuminated letters and graphics. The letters are comprised of a metal or plastic housing, referred to as a U-shaped channel due to the squared "U" shape of a cross section of the housing, with the top opening of the housing often covered with a colored acrylic face. Neon has been the traditional light source for channel letter signs, but like LED EXIT signs, light emitting diode (LED) technology is emerging as another light source for the channel letter sign market. Figure 6 shows an example of both a neon and LED channel letter sign.

FIGURE 6: NEON (TOP) AND LED (BOTTOM) CHANNEL LETTER SIGNS WITH ACRYLIC FACE ON THE "C" OF THE LED SIGN

LED channel letter signs use LED technology as an alternative to traditional neon technology. Instead of neon transformer and gas-filled neon tubes that have been bent and shaped to follow the U-shaped channel, the LED signs use an LED driver and various flexible strips of white or colored LEDs that follow the channel. The LED signs can replace both new and existing neon signs. There are many manufacturers currently selling LED channel letter sign technology, thus making the products easily attainable.

An LED is a semiconductor that is completely covered in epoxy. It emits light when there is a proper amount of current in the LED. Often used as little indicator lights on everything from large appliances to portable electronics, the small, low-output LED is a fairly mature technology. However, advances in LED technology have made them brighter and more efficient, thereby expanding the application of LED to other markets. In the sign industry, LED is a new technology.

The operation of the LED channel letter sign is the same as that of the neon channel letter sign from the perspective of the end-user. The LED sign can be turned on and off when needed, or wired up to a photocell or time-clock in the same way as a neon sign.

OBJECTIVE

The objective of the project is to show any incremental energy savings and demand reduction of LED channel letter signs over traditional neon channel letter signs. The project assesses and verifies energy savings and demand reductions by measuring the performance of the technologies in a controlled laboratory environment at the Southern California Lighting Technology Center (SCLTC). Photometric tests, also conducted at the SCLTC, demonstrate the differences and similarities between the LED and neon channel letter signs.

LED channel letter lighting is currently rebated from $2/ft. of letter to $6/ft of letter for red LED channel letter signs only. The latest advancements in LED technology may allow other colors such as orange (amber), yellow, green, blue, and white to compete with potentially less efficient traditional neon systems.

BACKGROUND

LED technology, sometimes referred to as Solid State Lighting, differs from traditional light sources in the way light is produced. The historical light sources are incandescent and fluorescent. In an incandescent lamp, a tungsten filament is heated by electric current until it glows or emits light. In a fluorescent lamp, an electric arc excites mercury atoms, which in turn emits ultraviolet (UV) radiation. The UV radiation strikes the phosphor coating on the inside of glass tubes, and is converted to visible light.

An LED, in contrast, is a semiconductor diode. The LED consists of a chip of semiconducting material treated to create a structure called a p-n (positive-negative) junction. When connected to a power source, current flows from the p-side or anode to the n-side, or cathode, but not in the reverse direction. Charge-carriers (electrons and electron holes) flow into the junction from electrodes. When an electron meets a hole, it falls into a lower energy level, and releases energy in the form of a photon (light).[i]

The specific color produced by LED lights depends on the materials used in manufacturing. LEDs are manufactured to produce many colors. There are a few popular ways to produce white light. One method is to combine red, green, and blue LEDs (referred to as RBG light), but this can be expensive. A less expensive method is to coat blue LED chip with yellow phosphor, but this can result in a low quality product. For a better quality product, blue LED chips can be coated with high quality phosphors, a method used by many high quality LED manufacturers.

Fluorescent light sources require a ballast to function, providing a starting voltage and then limiting electrical current to the lamp. LEDs also require additional electronics, called drivers. The driver converts line power to the appropriate voltage and current.

LED's are directional in nature and have potentially higher application efficiency than other light sources in specific lighting applications. Because fluorescent and standard "bulb" shaped incandescent lamps emit light in all directions, much of the light produced by the lamp is lost within the fixture, reabsorbed by the lamp, or escapes from the fixture in a direction that is not useful for the intended application. For many fixture types it is not uncommon for 40-50% of the total light output of the lamp(s) to be wasted in a direction not intended for the purpose of the light. LEDs emit light in a specific direction and do not require reflectors or diffusers.

Graphic from DOE, EERE

FIGURE 7: TRADITIONAL INCANDESCENT OR NEON LIGHT OUTPUT LOSS[ii]

SIGN INDUSTRY

In the sign industry, LED is a newer technology. LED technology has been used as an alternative to incandescent technology in exit sign lighting and is currently being used as an alternative to traditional neon technology for open signs used in many businesses. The directional nature of a LED can potentially make it an ideal technology for channel letter signs, an application in which light is wanted on the face of the letter. Channel letter signs are usually illuminated with neon, which is formed by hand to fit inside the channel.

CODES AND STANDARDS

Current Title 24 standards require a maximum Lighting Power Density (LPD) of 12 W/sq. ft. for internally illuminated signs using magnetic ballasts. However, because the source light is typically neon, channel letter signs are not covered by Title 24 and therefore do not have to meet this LPD requirement.

COST

The California Sign Association and the International Sign Association performed a survey in partnership with SCE to determine the relative costs of producing LED versus neon channel letters. The sign builders surveyed were larger-volume builders whose costs should be representative of the industry at large. Results indicate, on average, the total cost of producing LED channel letters is greater than the cost to produce comparable neon letters. The relative production costs ranged from one manufacturer that claims LEDs are 15% less expensive to produce, up to another manufacturer that claims LEDs are 23% more expensive to produce.

There are three basic components that comprise the total production cost: manufacturing labor, installation labor, and material cost. The survey results for each component are discussed, below.

MANUFACTURING LABOR

All survey participants indicated the labor cost to manufacture neon tubes that are housed in the channel letter is, on average, 20% more than the LED channel letter strips. The builders' estimated costs for neon manufacturing labor ranged between 10% and 45% higher than LED manufacturing labor.

INSTALLATION LABOR

All survey participants indicated the labor cost to install neon channel letters is, on average, 25% more than the labor cost associated with LED channel letter strips. The builders' estimated costs for neon installation labor ranged between 10% and 50% higher than LED installation labor.

MATERIAL COST

All survey participants indicated the material costs to produce LED channel letters is higher than for neon channel letters, costing approximately 26% more. The builders' estimated costs for LED materials ranged between 17% and 40% higher than neon materials.

METHODOLOGY

All testing was conducted at Southern California Lighting Technology Center (SCLTC) in Irwindale, California. The lab allowed for a consistent environment to measure the performance of the signs. The ambient temperature was kept at 73° Fahrenheit throughout the test. The facility featured an internal, light-isolated dark room lined with black stage curtains. The test area was 10 feet deep, 5 feet wide and 8 feet high. This environment provided a near-black area to collect light-related values with negligible interference from external sources.

The measurements taken at the SCLTC laboratory each verified some uncertainties associated with the technology. One of the uncertainties with the technology is the brightness, or luminance, of the LED compared to the neon channel letter. The purpose of the luminance measurement is to relatively quantify the brightness of LED channel letter signs in comparison to that of neon signs. Another uncertainty is the demand of the technology. The purpose of the demand measurements is to verify any demand reduction when going from neon to LED technology.

SCLTC Test Sign

The sign used for all testing was a Southern California Edison sign displaying the acronym "SCE". For uniformity in all the photometric tests, only the "S" was tested. The "C" and "E" were covered with black stage curtains to avoid any light disturbance.

For power testing, the entire sign was plugged in and measured.

Independent Variables

Lamp Technology

A total of 2 neon and 6 LED manufacturers were tested. One hundred twelve tests were performed, of which 28 tested neon channel letter lighting and 84 tested LED channel letter lighting. The tests included various combinations of colored light and colored faces on the channel letter.

Lamp Color

Six lamp colors were tested: red, orange, yellow, green, blue, and white. Some manufacturers had more than one white color (e.g. white and warm white). In these cases, all white products were tested.

Acrylic Face Color

Six acrylic face colors were tested: red, orange, yellow, green, blue, and white. The acrylic faces were 1/8" thickness. All colored faces were tested with the white light source. In addition, each face color was tested with the matching lamp color (e.g. red lamp with red face, orange lamp with orange face).

Dependant Variables

Minimum, Maximum, and Average Luminance

Luminance data is obtained from two tests. The results from the luminance camera data used with the Photolux software determines the minimum, maximum, and average luminance values for the white light sources (neon and LED) with a white acrylic face. The results from the chroma meter determine spot luminance and color coordinates for seven points along the S stroke. These seven points are discussed in more detail in the procedures section, below.

COLOR COORDINATES

The results from the chroma meter determine color coordinates for seven points along the middle of the stroke of the letter S. These color coordinates allow color comparison of the neon and LED white light sources with a colored acrylic face, as well as the neon and LED colored light sourced with a matching color acrylic face. The color coordinates also result in a visual representation of the true color of the lights. In other words, by plotting the color coordinates on a chromaticity diagram, one can determine if a yellow light with a yellow face falls within the visual spectrum of "yellow".

CONNECTED LOAD

The signs were plugged in and logged to obtain power data that can be directly compared across products. These power data are also used to determine product efficiency, described below.

EFFICIENCY

The power data is combined with the sign luminance to provide an efficiency value of average luminance per watt, a unit used in this test for comparison across products. It is well known that LED wattage is significantly lower than neon. However, lower wattage is only of value if the luminance requirements are still met. Therefore, the average luminance per watt value allows an "apples to apples" comparison across the two product types.

LUMINANCE MEASUREMENTS

EQUIPMENT

LUMINANCE CAMERA

Area, total, and maximum luminance (cd/m^2) values for each test configuration were measured using a tripod-mounted Nikon Coolpix 5400 camera with installed fisheye lens. Images were recorded using the camera's memory card to allow for later transfer to a computer for analysis. Figure 8 shows the camera.

FIGURE 8: LUMINANCE CAMERA

This measurement technique utilized the camera's image sensor as an array of light sensors. Using specialized luminance software, Photolux 2.0 by ENTPE, similar images were taken at different apertures and shutter speeds and were combined and processed, resulting in false-color luminance maps. Area, total, and maximum luminance values were then obtained from these maps.

PHOTOLUX

The luminance was measured by using the Photolux system, based on the use of a calibrated CCD camera, the Nikon shown in Figure 8, equipped with a fish-eye lens. The Photolux software produces from one or more photos (with different exposures) a luminance map providing a quasi-continuous representation of the luminance of a scene. Figure 9 shows a luminance map from the test.

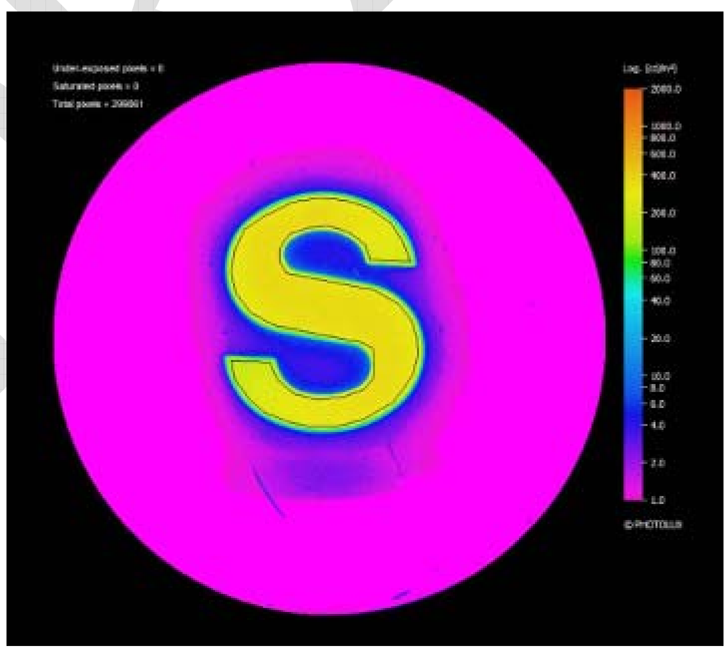

FIGURE 9: PHOTOLUX LUMINANCE MAP

The scale on the right hand side of the Photolux image shows the color index for the luminance scale. The brightest or most luminescent parts of the image (up to 2,000 cd/m^2) are represented by the red-orange end of the scale, with the pink-purple hues displaying the darkest or least luminescent parts of the image (down to 1 cd/m^2). The pink areas show the efficiency of the black stage curtains at cutting out ambient light.

For this test a series of fourteen photos were taken and processed to produce the luminance map. Aperture and shutter speed for each photo are shown in Table 2.

TABLE 2: CAMERA EXPOSURE SETTINGS

PHOTO	SHUTTER SPEED	APERTURE
1	2	2.8
2	1	3.1
3	1/2	3.5
4	1/4	4
5	1/8	4.4
6	1/15	5
7	1/30	5.6
8	1/60	6.3
9	1/125	5.6
10	1/250	5
11	1/500	5.6
12	1/1000	6.3
13	1/2000	7.1
14	1/4000	7.9

CHROMA METER

Spot luminance and chromaticity values for each product were measured using a handheld Konica Minolta CS-100A chroma meter with integrated LCD. Values were recorded and transferred to a computer for analysis. Figure 10 shows a picture of the chroma meter.

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FIGURE 10: CHROMA METER

STANDARD PHOTOGRAPHS

SONY DSC-V1 CAMERA

In addition to the photographs taken for the luminance measurements and Photolux analysis, a Sony DSC-V1 camera was used to take a standard photo of each test configuration. This allowed for a visual comparison of all tested light sources.

DEMAND MEASUREMENTS

EQUIPMENT

POWER QUALITY LOGGER (PQL)

Demand values for each sign configuration were measured using an Aemc Instruments PQL 120 power meter with integrated logging capability. Values were recorded using the internal memory for later transfer to a computer for analysis. Figure 11 shows the PQL 120.

FIGURE 11: DEMAND AND POWER QUALITY LOGGER

DETAILED PROCEDURES

LUMINANCE AND PHOTOLUX

Each of the neon and LED channel letters was measured using the same basic routine. First, the channel letter was set up with neon or LED technology following manufacturer specifications. The tri-pod mounted luminance camera was positioned one horizontal foot from letter to lens, at the same height as the letter. The sign was turned on and the time recorded. The neon technology was allowed to warm up, and the acrylic letter face was left off. Luminance and chromaticity values were measured with the chroma meter. Seven luminance, color coordinates, and power measurement readings were taken, and the time was recorded. The seven spot measurements were taken along the stroke of the letter "S", at the middle of the width of the stroke, as shown in Figure 12.

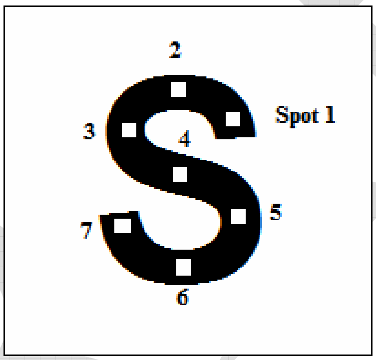

FIGURE 12: MEASUREMENT POINTS ALONG "S" STROKE.

For both neon and LED, a 1/8" acrylic face was placed on the channel letter, and the seven measurements were recorded. This was repeated for all 5 colored faces (red, orange, yellow, green and blue), followed by the white acrylic face.

After the seven spot measurements were taken with the white acrylic face, a set of images was taken with the fisheye lens. These images of the white light source plus white face were taken for later processing with the specialized Photolux luminance software.

Additional tests repeated the spot measurement procedure using neon and LED colored light sources and matching acrylic face (i.e. blue light source with blue face).

STANDARD PHOTOGRAPHS

After the spot measurement procedure was completed for each configuration, standard pictures were taken with the Sony DSC-V1 camera. The shutter speed was set to 1/15 seconds with an aperture of 1/8. The camera was mounted at a distance of 9 feet from the letter.

DEMAND MEASUREMENTS

Each of the products was measured using the same basic routine. The power logger (PQL) was connected to a line voltage (approximately 110 VAC at 60 Hz) and configured to record in 5-second intervals for the duration of the testing period. The SCE sign was connected to the logger which recorded throughout the testing period. After the SCE sign was turned off, the logger continued to record as each configuration was tested. The logger was not turned off until the final test of the day was completed and the sign was turned off.

RESULTS

OVERVIEW

Data was downloaded from equipment memory and imported into appropriate software for processing and analyzing luminance, demand, and startup characteristics.

NAMING CONVENTIONS IN RESULTS SECTION

Products are not directly identified in this report. Instead, a generic naming convention was created for each product tested. The tests are organized by neon and LED sets, which is the first part of the generic name. This is followed by one letter to describe the color of the light source and then an additional letter to describe the color of the acrylic face. For example, the first neon set with a red light source and red face would be named “Neon-Set 1-R-R”.

Some manufacturers have two different white light sources, such as white and warm white. To differentiate between these two products, white light sources include a number after the W. For example, *LED-Set 4-W1-R* and *LED-Set 4-W2-R* represent the same LED manufacturer, with two white light sources tested with the red face.

Tested products are listed by manufacturer in Appendix A, but are not identified with their generic name used in the analysis.

PHOTOLUX RESULTS- WHITE LIGHT SOURCE WITH WHITE FACE

PROCESSING

Images for each sign were downloaded from the camera’s memory card, and imported into the specialized luminance software for processing. False color luminance maps were created from the data. Figure 13 shows the false color luminance map for a white LED light source with a white face (*LED-Set 2-W1-W*).

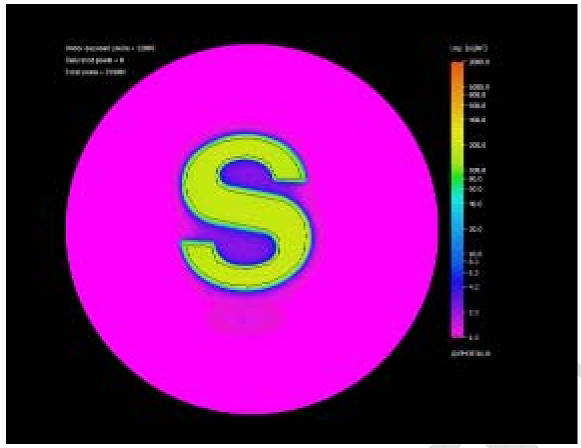

FIGURE 13: FALSE COLOR LUMINANCE MAP FOR *LED-SET 2-W1-W* SHOWING OUTLINE OF LUMINANCE AREA STATISTIC ZONE

Area, maximum and minimum luminance (cd/m^2) values were obtained from these maps. Area luminance was defined as the average luminance of the area within the "S" region, shown in bright reds, yellows, greens and some blues. The area excludes the area surrounding the "S" that comprises the rest of the map, shown in dark blues and pinks. The area was obtained by using a statistic zone drawn around the perimeter of the "S". Figure 13 includes the statistic zone, drawn as a thin black line around the edges of the "S", for *LED-Set 2-W1-W*.

Area luminance was obtained through direct output of the specialized Photolux luminance software. Figure 14 shows the statistics display for *LED-Set 2-W1-W* from which the average luminance of 187.51 cd/m^2 is obtained for the statistic zone outlined in Figure 13.

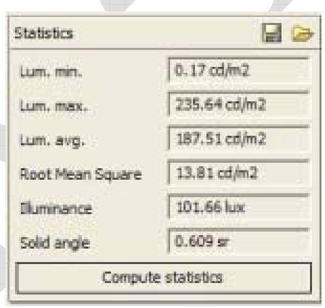

FIGURE 14: LUMINANCE STATISTICS DISPLAY

The Photolux images were also used to determine the maximum and minimum luminance along the middle of the stroke of the letter, which represents the source of the neon or LED light. Ideally, the luminance values would be uniform across the face of the letter, such that dark and light spots would not be visible to the naked eye. In reality, nearly all products tested showed at least some contrast across the letter surface, though some products performed better than others. The maximum and minimum luminance test revealed that contrasting bright and dark spots are more likely to occur with LED strip lighting. This spotting is due to the spacing of the clustered LEDs along the strip, as shown in Figure 15. The arrow in Figure 15 highlights a space between two LED clusters where one might expect to see a dark spot between the light LED clusters.

FIGURE 15: POSSIBLE CONTRASTING LIGHT AND DARK SPOTS BETWEEN LED CLUSTERS

The Photolux image in Figure 16 displays the maximum and minimum luminance values along the source of both a neon light source and an LED light source. As expected, the neon light shows little contrast, as indicated by the small difference between the maximum and minimum points, while the LED shows greater contrast. However, it is important to note that not all contrast that is picked-up by the Photolux software is visible to the human eye, as evidenced by luminance photos of the identical neon and LED products in Figure 17.

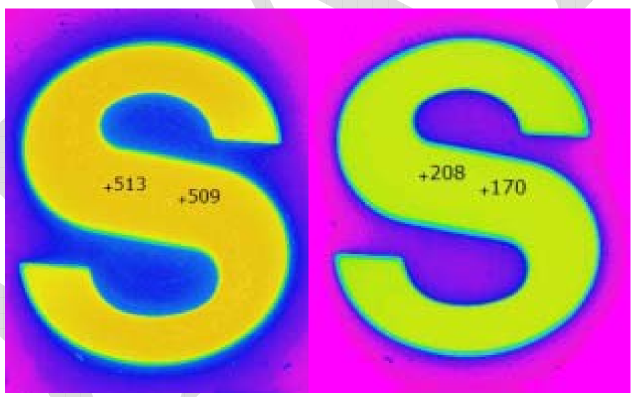

FIGURE 16: PHOTOLUX SOFTWARE MAXIMUM AND MINIMUM LUMINANCE POINTS FOR NEON (LEFT) AND LED (RIGHT) PRODUCTS

FIGURE 17: LUMINANCE PHOTOS OF THE NEON (LEFT) AND LED (RIGHT) PRODUCTS DISPLAYED IN FIGURE 16.

ANALYSIS

The following figures compare white Neon and LED light sources with white faces. In comparing neon light sources with LED light sources, there was considerable variability between the two groups. As seen in Figure 18 through Figure 24, there was also significant variability within both neon and LED lighting.

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Note that one of the LED products was tested with twice the number of manufacture recommended LEDs for the size of the channel letter. This product name is followed by a "2x" (for two-times the amount), and is apparent by the nearly double maximum luminance value in Figure 18. In many cases, if greater luminance is desired, the number of LEDs per letter may be increased.

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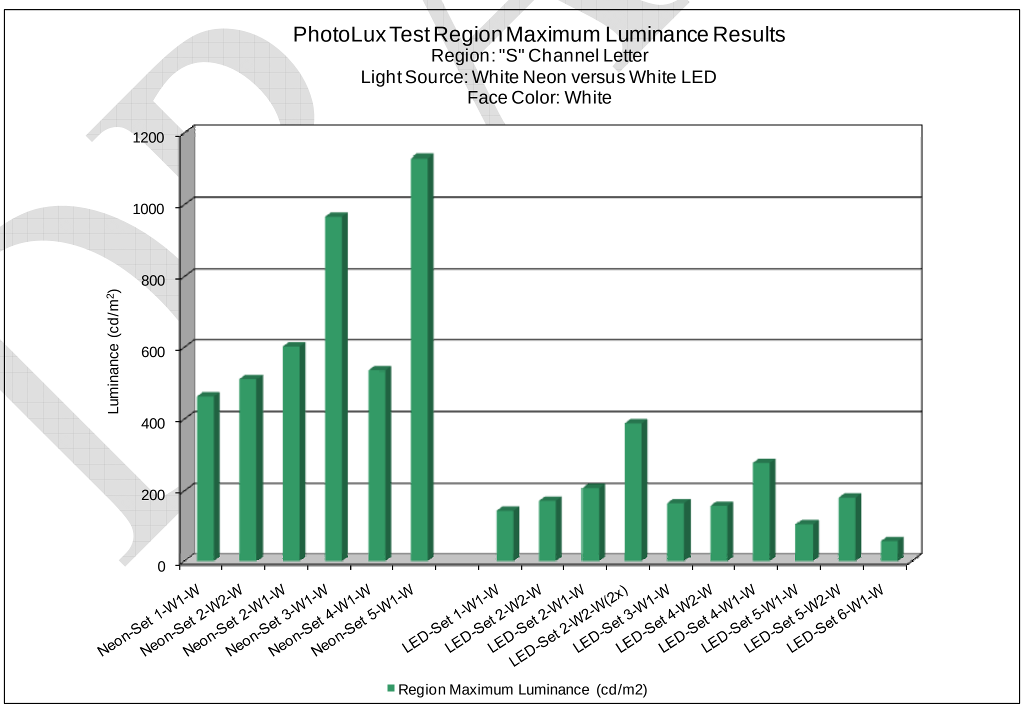

FIGURE 18: PHOTOLUX REGION MAXIMUM LUMINANCE RESULTS

As seen in Figure 18, all of the neon lights had higher maximum luminance measurements than the LED source light. For a visual comparison, the light source with the highest maximum luminance (1130.0 cd/m^2) is pictured beside the light

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source with the smallest maximum luminance (58.1 cd/m^2) in Figure 19. Figure 20 compares the neon with the lowest maximum luminance (*Neon-Set 1-W1-W*) with the LED with the highest maximum luminance (*LED-Set 2-W2-W(2x)*).

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FIGURE 19: PHOTO COMPARISON OF REGION WITH HIGHEST (NEON) AND LOWEST (LED) MAXIMUM LUMINANCE

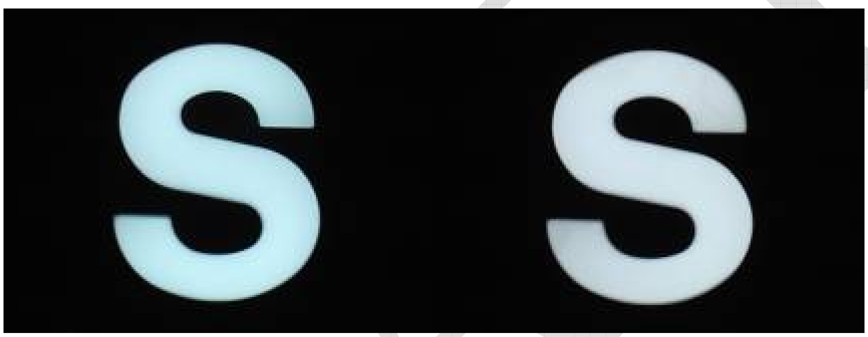

FIGURE 20: PHOTO COMPARISON OF NEON WITH LOWEST MAXIMUM (LEFT) AND LED WITH HIGHEST MAXIMUM (RIGHT) LUMINANCE

The degree to which a light source has measurable contrast can be evaluated by a contrast ratio. The ratio of the maximum luminance over minimum luminance provides a metric for easy comparison between products. A ratio of one represents a “perfect” light source with no measurable contrast. As the ratio diverges from one, the more that light source produces measurable contrast. Figure 21 displays the contrast ratio for all tested white light source with white acrylic face configurations.

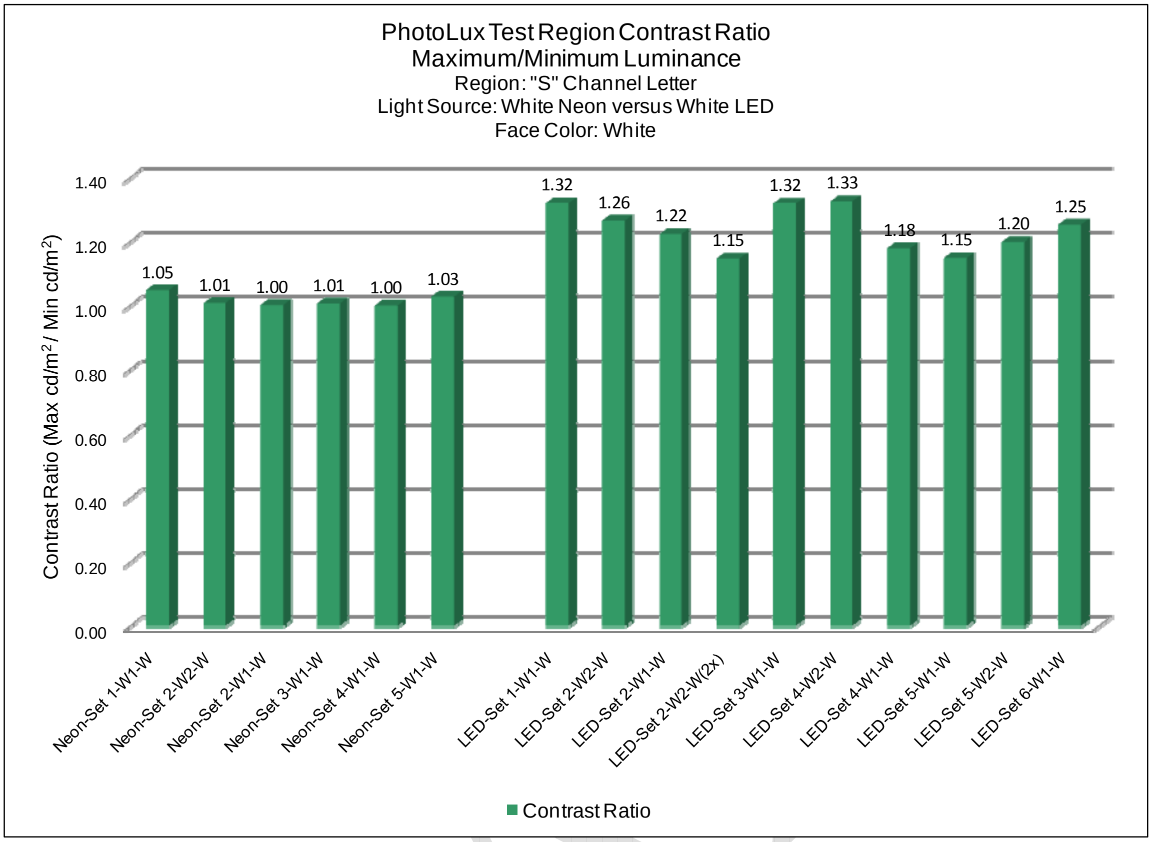

FIGURE 21: REGION CONTRAST RATIO FOR NEON VERSUS LED

It is apparent that, on average, the neon light sources have significantly lower contrast, meaning there is a more even distribution of light across the face of the letter.

Having a ratio close to one signifies a more uniform region with less contrast. A high ratio indicates greater contrast, and may appear spotty to the naked eye. However, this is not always the case, as shown in Figure 22. The contrast in the image on the right is not visible to the naked eye.

FIGURE 22: *NEON- SET 2-W2-W* (LOWER CONTRAST OF 4) VERSUS *NEON-SET 5-W1-W* (HIGHER CONTRAST OF 30)

During the Photolux test, power measurements were taken on all the products. The neon products were all larger consumers than the LED products. On average, the neon products consumed 68.1 watts with a range of 44.3 watts (*Neon-Set 4-W1-W*) to 102.23 watts (*Neon-Set 3-W1-W*). The LED products consumed, on average, 24.0 watts, nearly one third of the average neon consumption. The LED products ranged from 13.9 watts (*LED-Set 6-W1-W*) to 42.0 watts (*LED-Set 4-W1-W*).

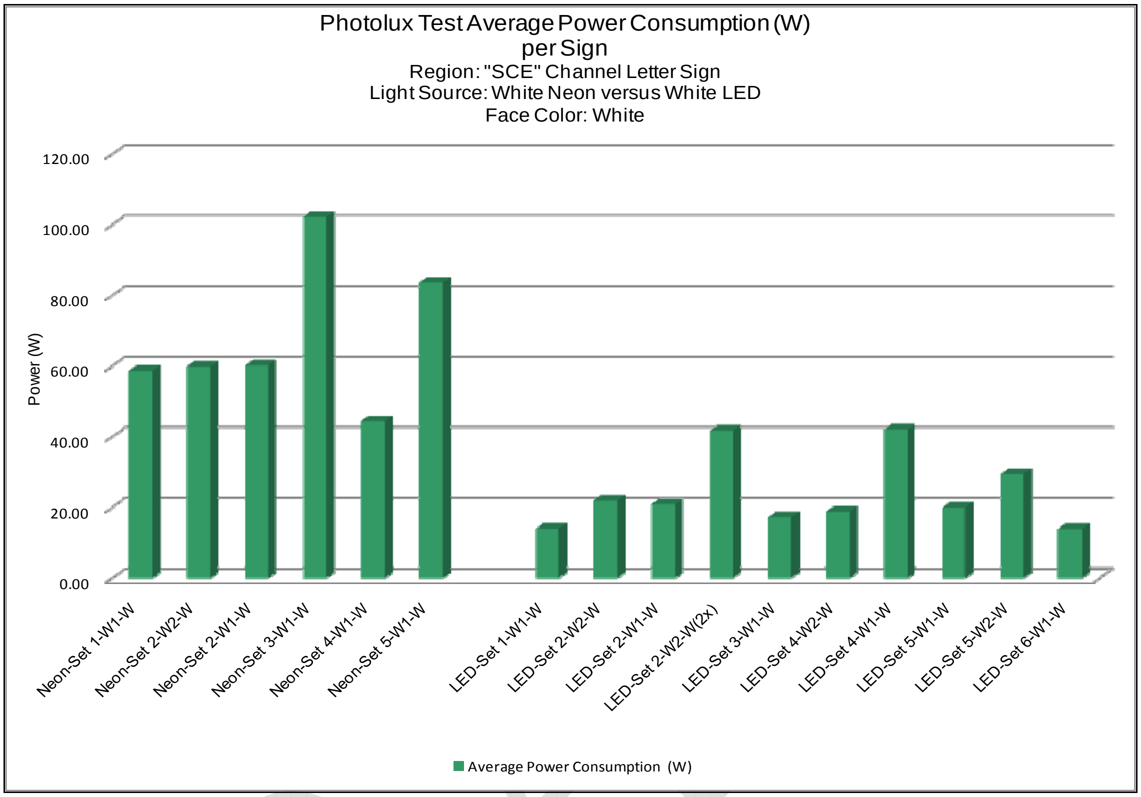

FIGURE 23: POWER CONSUMPTION OF NEON VERSUS LED

The Photolux software was used to determine the average luminance across the face of the “S” region. This average luminance was used to determine efficiency in average luminance per watt. Efficiency is reported, for each product tested, as shown in Figure 24. On average, the neon products were more efficient, with an average efficiency of 9.3 cd/m^2/Watt. The LEDs had an average efficiency of 6.6 cd/m^2/Watt. While the two most efficient products were neon (*Neon-Set 4-W1-W* and *Neon-Set 5-W1-W*) and stood out from all the tested products, the majority of the LED products were on par with *Neon-Set 1-W1-W* through *Neon-Set 3-W1-W*. The best LEDs were more efficient than the worst neon lamps.

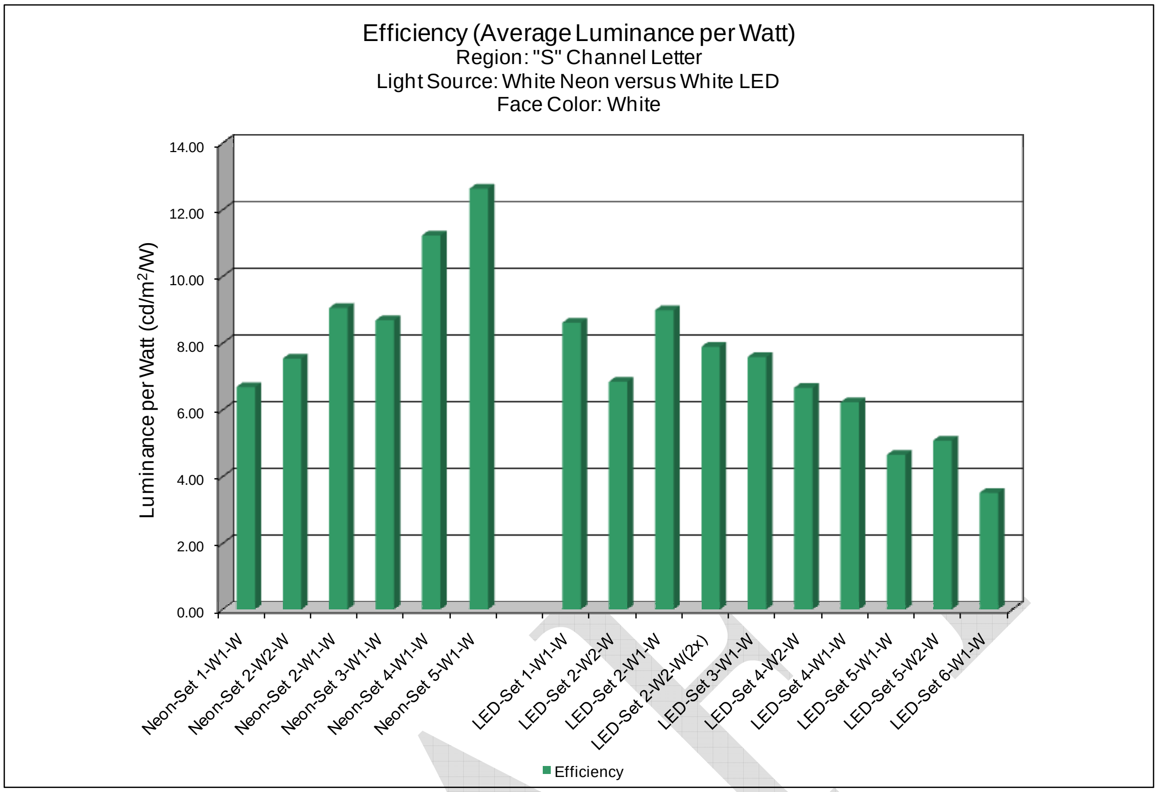

FIGURE 24: EFFICIENCY (LUMINANCE/WATT) OF ALL TESTED NEON AND LED PRODUCTS

CHROMA METER RESULTS- ALL LIGHT SOURCE COLORS WITH ALL FACE COLORS

PROCESSING

Images of test configurations for all color combinations were downloaded from the camera's memory for visual comparison of photometry results. Spot luminance (cd/m^2), and chromaticity (X and Y coordinates) values were transferred from the chroma meter and imported into Microsoft Excel for analysis.

The data was arranged by product to create averages across the seven spot measurements. The data was then averaged and reported by technology type.

ANALYSIS

LUMINANCE

While Figure 20 showed an example in which the contrast ratio of the LED is not quite visible to the human eye, Figure 25 shows three letters with fairly visible contrast ratios next to a neon letter with a low contrast ratio. In many cases, high contrast ratios were more visible with the colored faces.

FIGURE 25: LUMINANCE PHOTO COMPARISON OF REGIONS WITH LOW CONTRAST RATIO (LEFT) TO HIGH CONTRAST RATIO (RIGHT) USING A WHITE LIGHT SOURCE AND BLUE FACE.

The images in Figure 25 are *Neon-Set 2-W1-B*, *LED-Set 4-W1-B*, *LED-Set 5-W1-B*, and *LED-Set 5-W2-B*, from left to right. The chroma meter luminance results are displayed in Table 2. The image on the far left has the highest average luminance across the seven spot luminance measurements.

TABLE 3: CHROMA METER RESULTS FOR FOUR WHITE LIGHT SOURCE PRODUCTS WITH BLUE FACE WITH VARYING CONTRAST

	Seven Spot Luminance Measurements									
Product	1	2	3	4	5	6	7	Min	Max	Avg
Neon-Set 2-W1-B	119.0	133.0	131.0	135.0	141.0	139.0	129.0	**119.0**	**141.0**	**132.4**
LED-Set 4-W1-B	79.6	68.4	56.7	89.0	108.0	104.0	101.0	**56.7**	**108.0**	**86.7**
LED-Set 5-W1-B	35.7	37.2	44.5	40.5	41.1	42.8	43.5	**35.7**	**44.5**	**40.8**
LED-Set 5-W2-B	13.4	14.5	16.6	14.6	15.6	14.1	14.9	**13.4**	**16.6**	**14.8**

All luminance and chromaticity values were averaged for each color and technology. Figure 26 shows the averaged luminance values for the neon and LED technologies with a white light source and a colored acrylic face. The face colors are displayed on the axis below the chart.

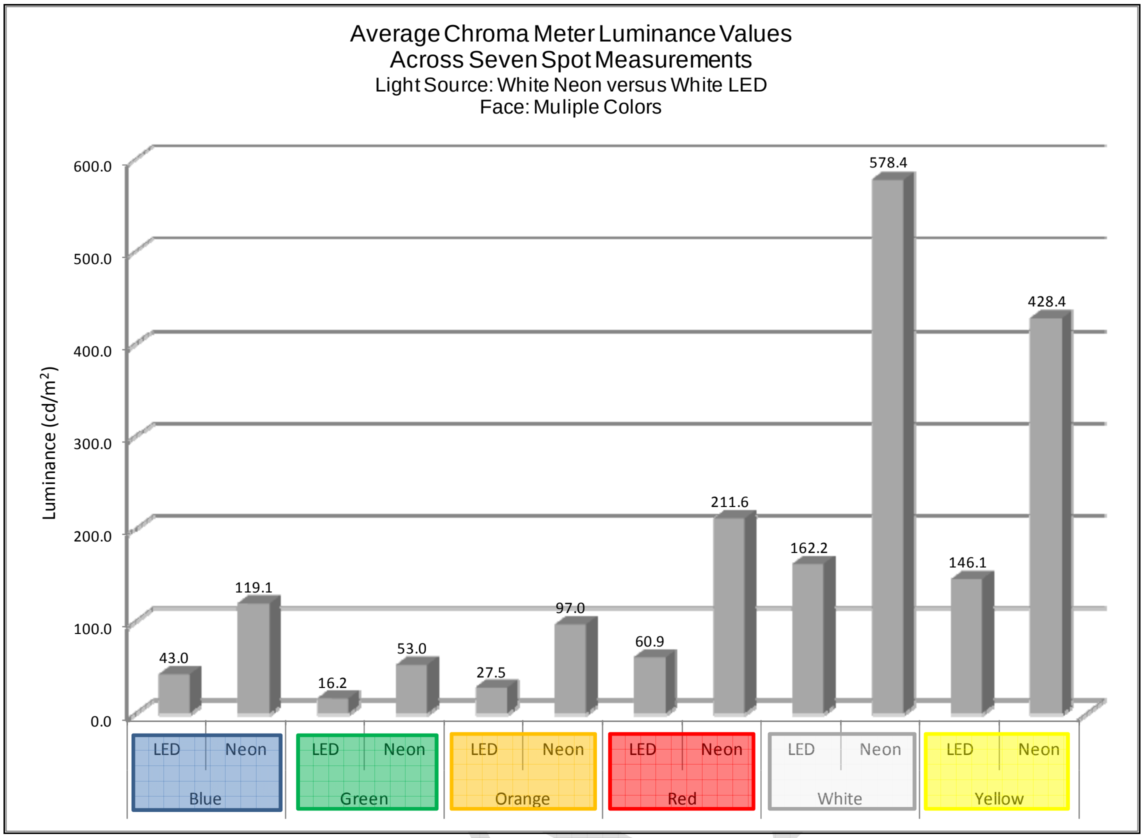

FIGURE 26: AVERAGE LUMINANCE VALUES BY LIGHTING TYPE ACROSS 7 SPOT MEASUREMENTS FOR WHITE SOURCE PLUS COLOR FACE

On average, neon has three times the luminance of LED technology. The difference was the least for the white light source with the blue acrylic face, in which the neon showed 2.7 times the luminance of the LED. Figure 27 shows the results averaged across the two technologies. Examining the individual products shows that some LEDs have luminance values approaching that of the least luminous neon product.

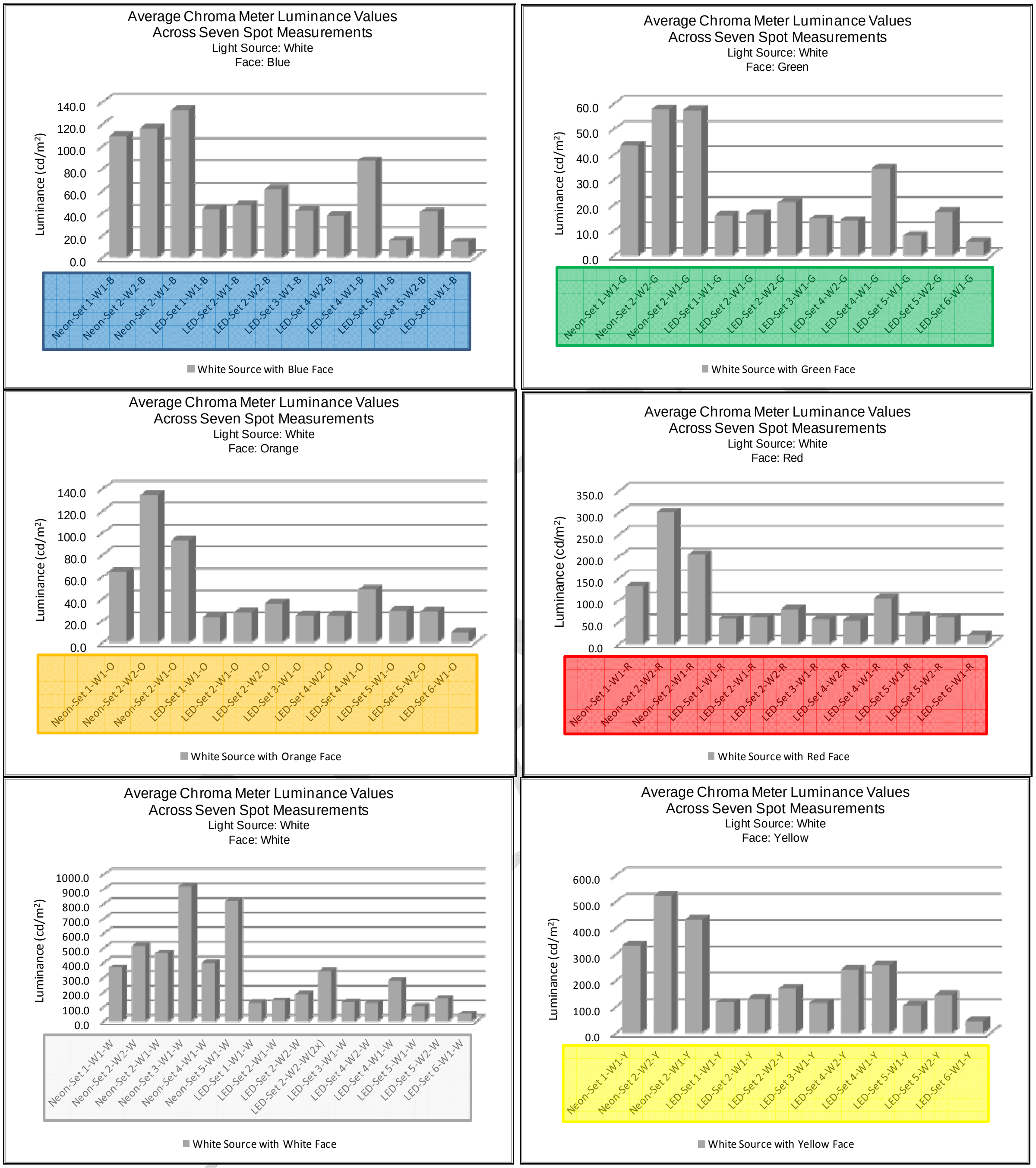

FIGURE 27: AVERAGE OF SEVEN CHROMA METER LUMINANCE VALUES, WHITE LIGHT SOURCE WITH COLORED FACE

LED-Set 4-W1 appears to have consistently higher luminance than the other LED products. The only exception is the doubled *LED-Set 2-W2-W(2x)* in the white source plus white face test.

The chart displaying the white light source with the white acrylic face supports the similar luminance charts from the Photolux analysis. Refer to Figure 18 in which the

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Photolux maximum luminance was charted. The same relative relationship is reported in the comparable white neon versus LED chroma meter chart displayed in Figure 18. This is a good indicator that the two testing procedures appropriately measure luminance data.

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Next, the averaged luminance values for the neon and LED technologies with a color light source and matching colored acrylic face were examined. The results are displayed in Figure 28. The color of the light source and face are represented in the axis below the chart.

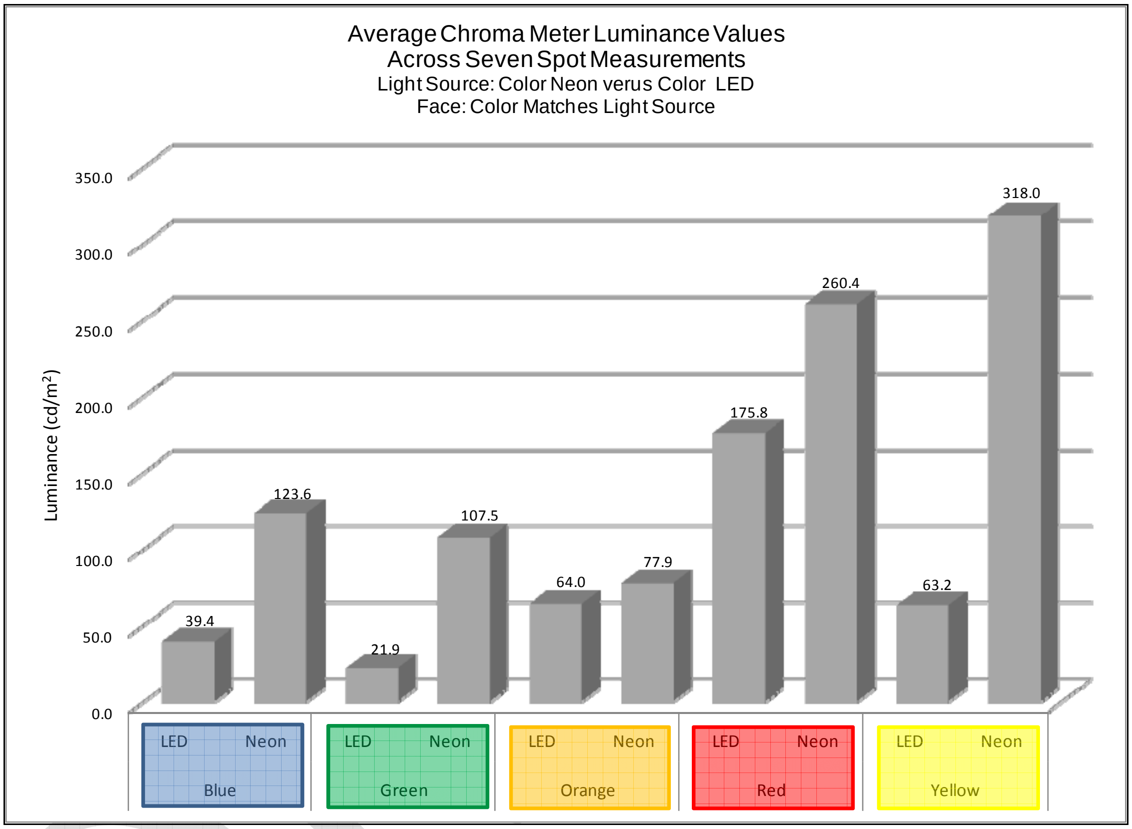

FIGURE 28: AVERAGE LUMINANCE VALUES BY LIGHTING TYPE ACROSS 7 SPOT MEASUREMENTS FOR COLORED LIGHT SOURCE PLUS MATCHING COLOR FACE

In comparing the average luminance values for the red and orange light sources, the neon is only 1.2 and 1.5 times brighter than the LED technology, respectively. The yellow light source with yellow face showed the greatest disparity, with the neon having 5 times greater average luminance than the LED products. Blue and green neon was 3.1 and 4.9 times more luminous than the LED products.

To determine if increasing the number of LEDs would decrease the disparity, an additional test was run in which the total number of blue and green LEDs was doubled. Figure 29 shows the effect of doubling the number of manufacturer recommended LED lights in the channel letter for both blue and green lighting. Doubling of the blue LED lights greatly increased the LED luminance.

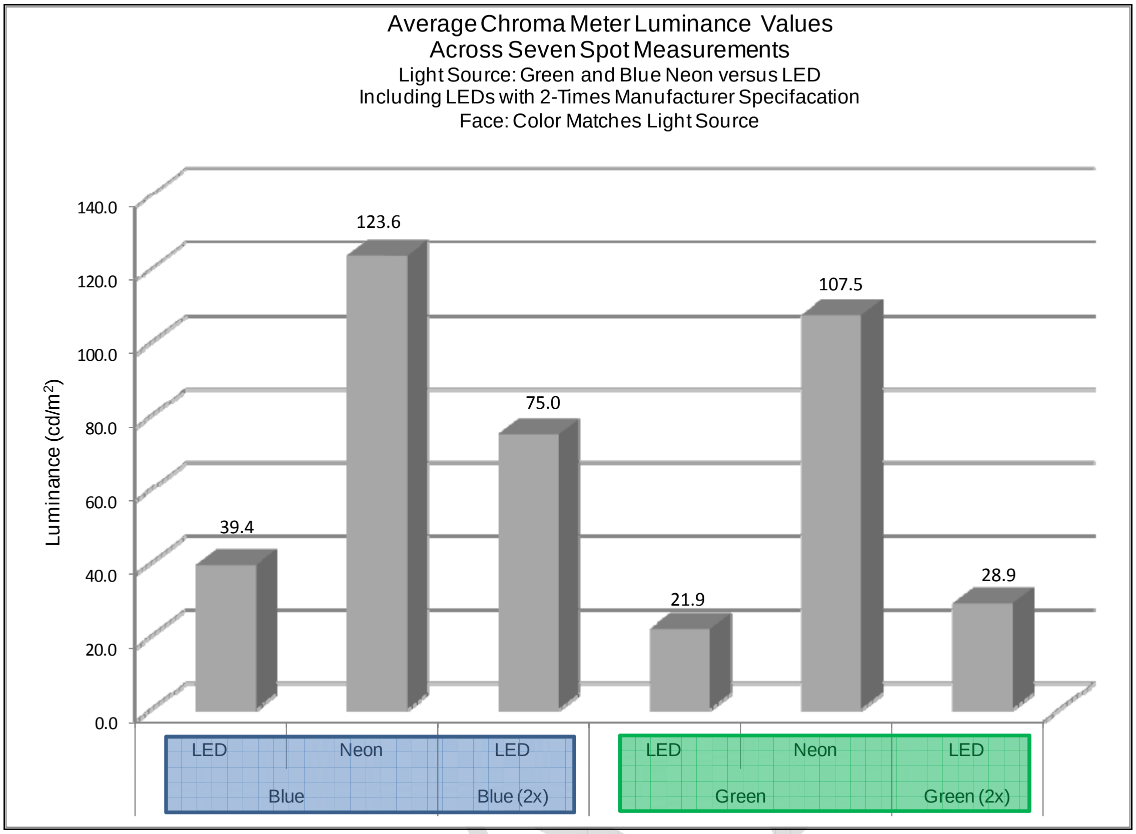

FIGURE 29: AVERAGE LUMINANCE VALUES BY LIGHTING TYPE ACROSS 7 SPOT MEASUREMENTS FOR GREEN AND BLUE COLORED LIGHT SOURCE PLUS MATCHING COLOR FACE

Figure 28 and Figure 29 show the results averaged across the two technologies. Examining the individual products shows that some LEDs have greater luminance and may be comparable to some neon with lesser luminance. Figure 30 displays the individual neon products beside the individual LED products.

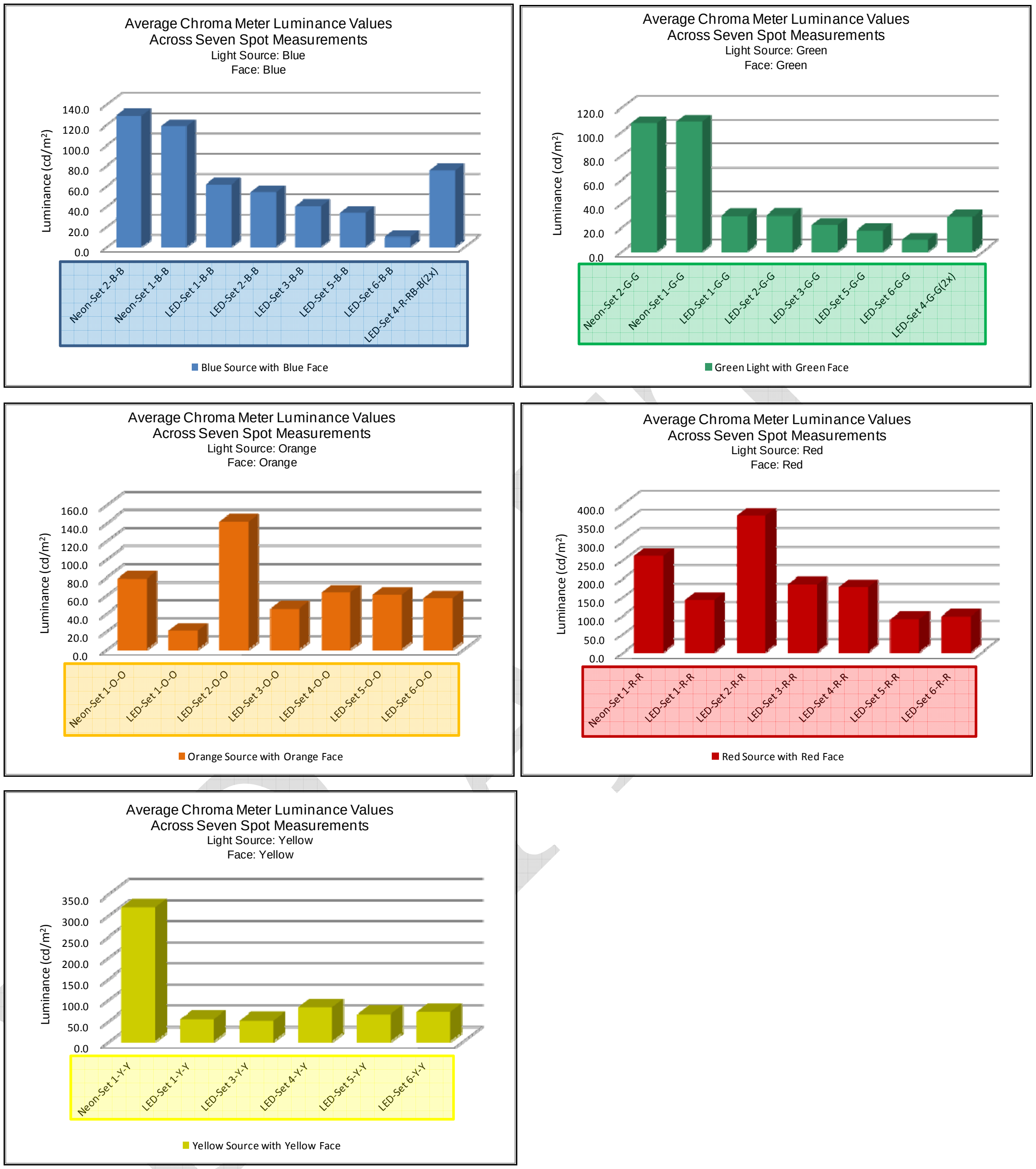

FIGURE 30: AVERAGE OF SEVEN CHROMA METER LUMINANCE VALUES, COLOR LIGHT SOURCE WITH COLOR FACE

As noted in the Photolux results, the luminance alone is not an adequate comparison without considering the energy consumption. The Demand Measurements section below summarizes the consumption and efficiency (Luminance/Watt) data.

COLOR COORDINATES

The chromaticity values (coordinates) were averaged across the seven measurement point for both the neon and LED technology. Table 4 displays the results using the white light source with color face data.

TABLE 4: COLOR COORDINATES FOR NEON VS. LED, WHITE LIGHT SOURCE WITH COLOR FACE

WHITE LIGHT TECHNOLOGY	FACE COLOR	COORD-INATE	1	2	3	4	5	6	7	AVERAGE
Neon	Blue	X	0.154	0.153	0.152	0.152	0.153	0.152	0.153	0.153
		Y	0.157	0.152	0.148	0.148	0.149	0.149	0.154	0.151
	Green	X	0.241	0.240	0.239	0.239	0.239	0.240	0.239	0.240
		Y	0.603	0.602	0.602	0.598	0.600	0.599	0.602	0.601
	Orange	X	0.654	0.653	0.654	0.654	0.655	0.655	0.654	0.654
		Y	0.345	0.346	0.345	0.345	0.344	0.344	0.345	0.345
	Red	X	0.660	0.660	0.661	0.660	0.660	0.661	0.661	0.661
		Y	0.339	0.339	0.338	0.339	0.339	0.338	0.339	0.339
	White	X	0.331	0.331	0.331	0.329	0.330	0.331	0.332	0.331
		Y	0.345	0.343	0.340	0.336	0.337	0.338	0.342	0.340
	Yellow	X	0.486	0.486	0.488	0.489	0.489	0.488	0.487	0.488
		Y	0.508	0.507	0.505	0.504	0.505	0.505	0.506	0.506
LED	Blue	X	0.150	0.149	0.149	0.150	0.150	0.149	0.150	0.150
		Y	0.145	0.141	0.141	0.144	0.142	0.141	0.143	0.142
	Green	X	0.245	0.242	0.243	0.245	0.244	0.244	0.243	0.244
		Y	0.574	0.572	0.575	0.574	0.575	0.574	0.551	0.571
	Orange	X	0.649	0.647	0.647	0.649	0.649	0.649	0.649	0.648
		Y	0.350	0.353	0.352	0.352	0.350	0.350	0.350	0.351
	Red	X	0.658	0.658	0.658	0.658	0.658	0.658	0.657	0.658
		Y	0.341	0.341	0.341	0.341	0.341	0.341	0.342	0.341
	White	X	0.342	0.341	0.342	0.342	0.342	0.343	0.340	0.342
		Y	0.339	0.339	0.342	0.342	0.341	0.340	0.339	0.340
	Yellow	X	0.494	0.493	0.493	0.533	0.493	0.493	0.493	0.499
		Y	0.499	0.501	0.501	0.501	0.501	0.500	0.500	0.500

The averaged data was then arranged to create comparisons between technologies for each technology color coordinate. Subtracting an LED chromaticity coordinate from a neon chromaticity coordinate results in a difference that expresses the relative color hue between the represented items of each value (i.e. blue neon chromaticity coordinates subtracted from blue LED chromaticity coordinates results in the blue color hue difference between neon and LED signs). Table 5 shows the comparisons between the chromaticity coordinates of white neon and LED light sources with color faces.

TABLE 5: AVERAGE CHROMATICITY COORDINATES FOR WHITE NEON AND LED WITH COLOR FACES

FACE COLOR	COORDINATE	NEON	LED	DIFFERENCE	REFERENCE
Blue	X	0.153	0.150	0.009	
	Y	0.151	0.142		
Green	X	0.240	0.244	0.030	
	Y	0.601	0.571		
Orange	X	0.654	0.648	0.008	
	Y	0.345	0.351		
Red	X	0.661	0.658	0.003	
	Y	0.339	0.341		
White	X	0.331	0.342	0.011	
	Y	0.340	0.340		
Yellow	X	0.488	0.499	0.012	
	Y	0.506	0.500		

The largest color hue difference was 0.030 units for the green color face, with the average neon being slightly more pure green than the average LED. The smallest color hue difference was for red, with both technologies falling well within the range of pure red.

These color coordinates are averaged across the technology types. For a table of the color coordinates of the individual products, refer to Appendix B.

The same analysis was performed for the color light sources with the matching color face. The chromaticity coordinates were averaged across the seven measurement points for both the neon and LED technology. Table 6 displays the results using the color light source with color face data.

TABLE 6: COLOR COORDINATES FOR NEON VS. LED, COLOR LIGHT SOURCE WITH COLOR FACE

WHITE LIGHT TECHNOLOGY	FACE COLOR	COORD-INATE	1	2	3	4	5	6	7	AVERAGE
Neon	Blue	X	0.139	0.139	0.139	0.139	0.139	0.139	0.139	0.139
		Y	0.058	0.056	0.055	0.056	0.056	0.057	0.059	0.057
	Green	X	0.185	0.183	0.183	0.182	0.183	0.183	0.184	0.183
		Y	0.439	0.741	0.459	0.459	0.742	0.741	0.739	0.617
	Orange	X	0.690	0.689	0.689	0.689	0.690	0.690	0.689	0.689
		Y	0.309	0.310	0.310	0.310	0.310	0.309	0.310	0.310
	Red	X	0.689	0.689	0.690	0.690	0.690	0.690	0.690	0.690
		Y	0.310	0.310	0.309	0.310	0.310	0.309	0.310	0.310
	Yellow	X	0.539	0.538	0.539	0.539	0.538	0.538	0.537	0.538
		Y	0.460	0.460	0.459	0.459	0.460	0.460	0.461	0.460
LED	Blue	X	0.138	0.138	0.138	0.138	0.138	0.138	0.138	0.138
		Y	0.049	0.047	0.046	0.048	0.047	0.068	0.047	0.050
	Green	X	0.166	0.163	0.163	0.164	0.166	0.164	0.167	0.165
		Y	0.738	0.736	0.734	0.736	0.735	0.736	0.734	0.736
	Orange	X	0.662	0.661	0.661	0.661	0.661	0.661	0.661	0.661
		Y	0.338	0.338	0.338	0.338	0.338	0.338	0.339	0.338
	Red	X	0.692	0.691	0.692	0.692	0.692	0.692	0.691	0.692
		Y	0.308	0.308	0.307	0.307	0.308	0.307	0.308	0.307
	Yellow	X	0.568	0.568	0.569	0.569	0.569	0.587	0.569	0.571
		Y	0.431	0.431	0.431	0.430	0.430	0.430	0.430	0.430

As with the white light source data, the average color light source coordinates were compared. Table 7 shows the difference between the color neon and LED chromaticity coordinates.

TABLE 7: AVERAGE CHROMATICITY COORDINATES FOR WHITE NEON AND LED WITH COLOR FACES

FACE COLOR	COORDINATE	NEON	LED	DIFFERENCE	REFERENCE
Blue	X	0.139	0.138	0.006	
	Y	0.057	0.050		
Green	X	0.183	0.165	0.120	
	Y	0.617	0.736		
Orange	X	0.689	0.661	0.040	
	Y	0.310	0.338		
Red	X	0.690	0.692	0.003	
	Y	0.310	0.307		
Yellow	X	0.538	0.571	0.044	
	Y	0.460	0.430		

Again, the largest color hue difference was for green. The average LED green light with green color face was 0.120 units closer to more pure green than the average neon product. The smallest color hue difference of 0.003 units was again for red, with both technologies falling well within the range of pure red.

The X and Y coordinates refer to the CIE 1931 chromaticity diagram. Figure 31 shows this diagram with the average chromaticity coordinates plotted. Plotting the chromaticity coordinates allows for a visual comparison of the color hues and where they fall with respect to the normal range of the reference color.

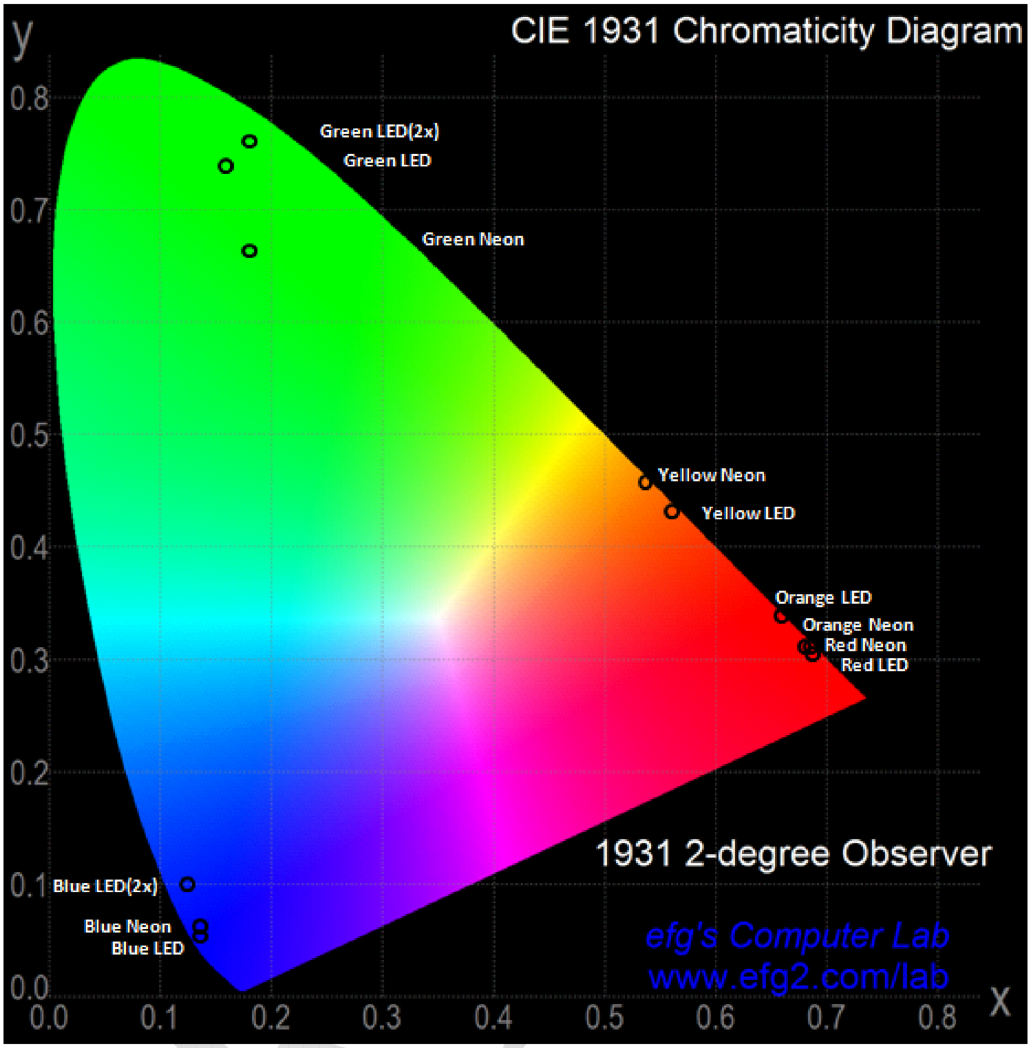

FIGURE 31: CHROMATICITY DIAGRAM WITH COORDINATES OF NEON AND LED COLOR LIGHT SOURCES WITH COLOR FACE

It is apparent that there is considerable overlap between the red and orange hues, with the orange coordinates typically falling within the red hue range. In addition, the average yellow hues tend towards orange, especially when considering the yellow LED.

These color coordinates are averaged across the technology types. For a table of the color coordinates of the individual products, refer to Appendix B.

DEMAND MEASUREMENTS

PROCESSING

Power data was collected with the Power Quality Logger. The power logger recorded the power every 5 seconds, and stamped each reading with the date and time. This data was imported into Microsoft Excel for analysis.

ANALYSIS

LAMP EFFICIENCY

One of the objectives of the channel letter tests was to determine if replacing neon with LED would result in energy savings without compromising sign quality. The efficiency comparison provides information to help to answer this question.

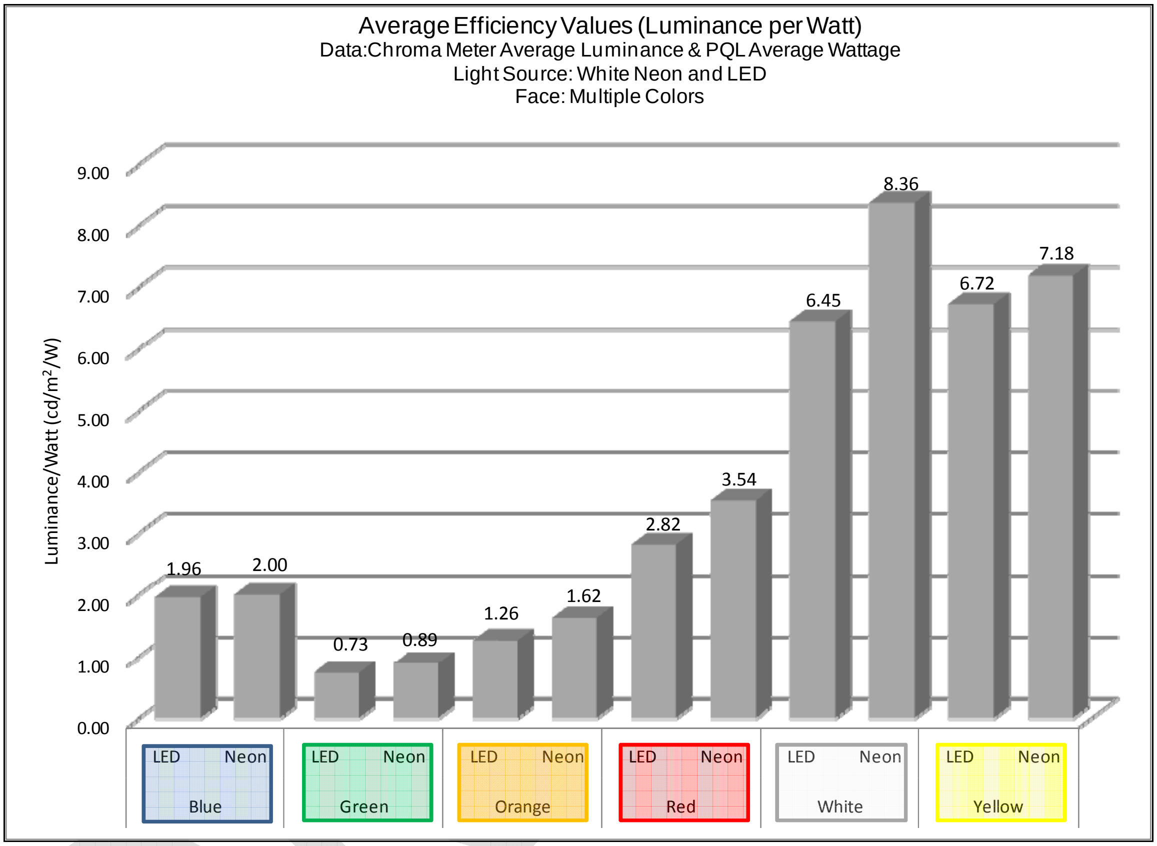

FIGURE 32: EFFICIENCY COMPARISON OF WHITE NEON AND LED WITH COLOR FACE

In general, the LED products are as efficient as the neon products, with efficiency values only slightly lower than the neon products. The exception is the white LED product, which is nearly two points lower on the efficiency scale.

The efficiency values of the individual products are examined in Figure 33 to determine if some LED products are more efficient than the neon products.

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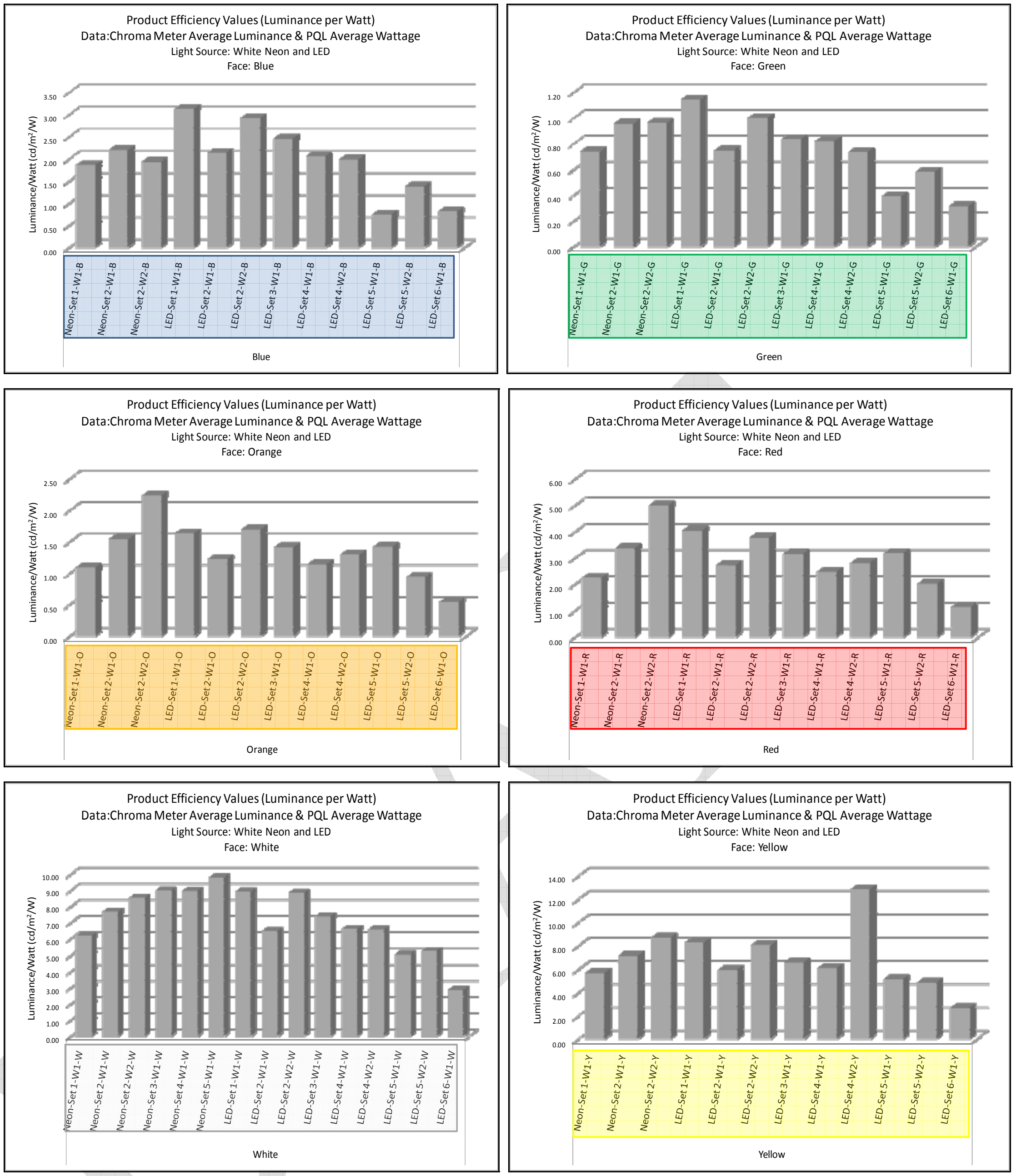

FIGURE 33: PRODUCT EFFICIENCY VALUES, WHITE LIGHT SOURCE WITH COLORED FACE

When comparing individual products, it is apparent that some white LED products with a colored acrylic face are more efficient than neon products. At least one green, red, and yellow LED product out-performed all neon products in efficiency.

Next, the efficiency of color LED and neon products were compared, as shown in Figure 34.

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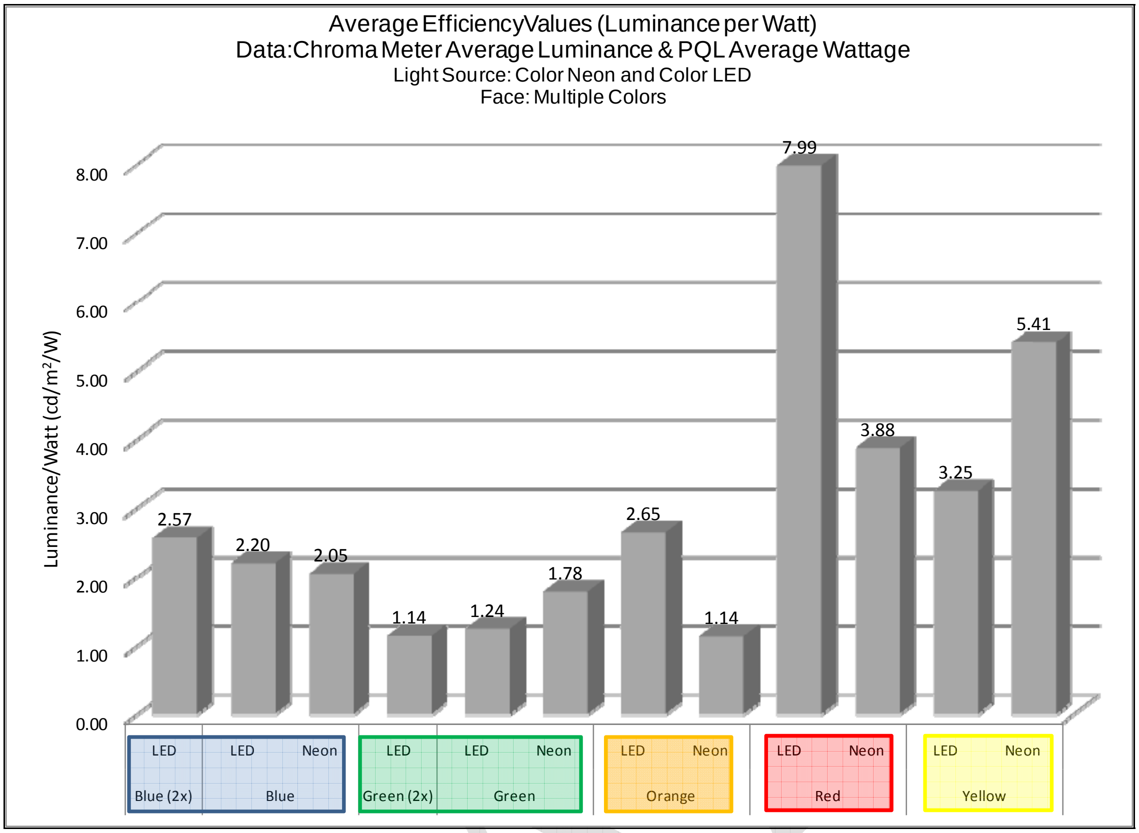

FIGURE 34: EFFICIENCY COMPARISON OF COLOR NEON AND LED WITH MATCHING COLOR FACE

When comparing the efficiency of the color light sources, the average efficiency values of the LED products are often comparable or better than the neon products. The blue, orange, and red LEDs are more efficient than the same color neon, with red being considerably more efficient. The green LED is only slightly less efficient than the green neon. However, the average yellow LED performed poorly with much lower efficiency than the yellow neon.

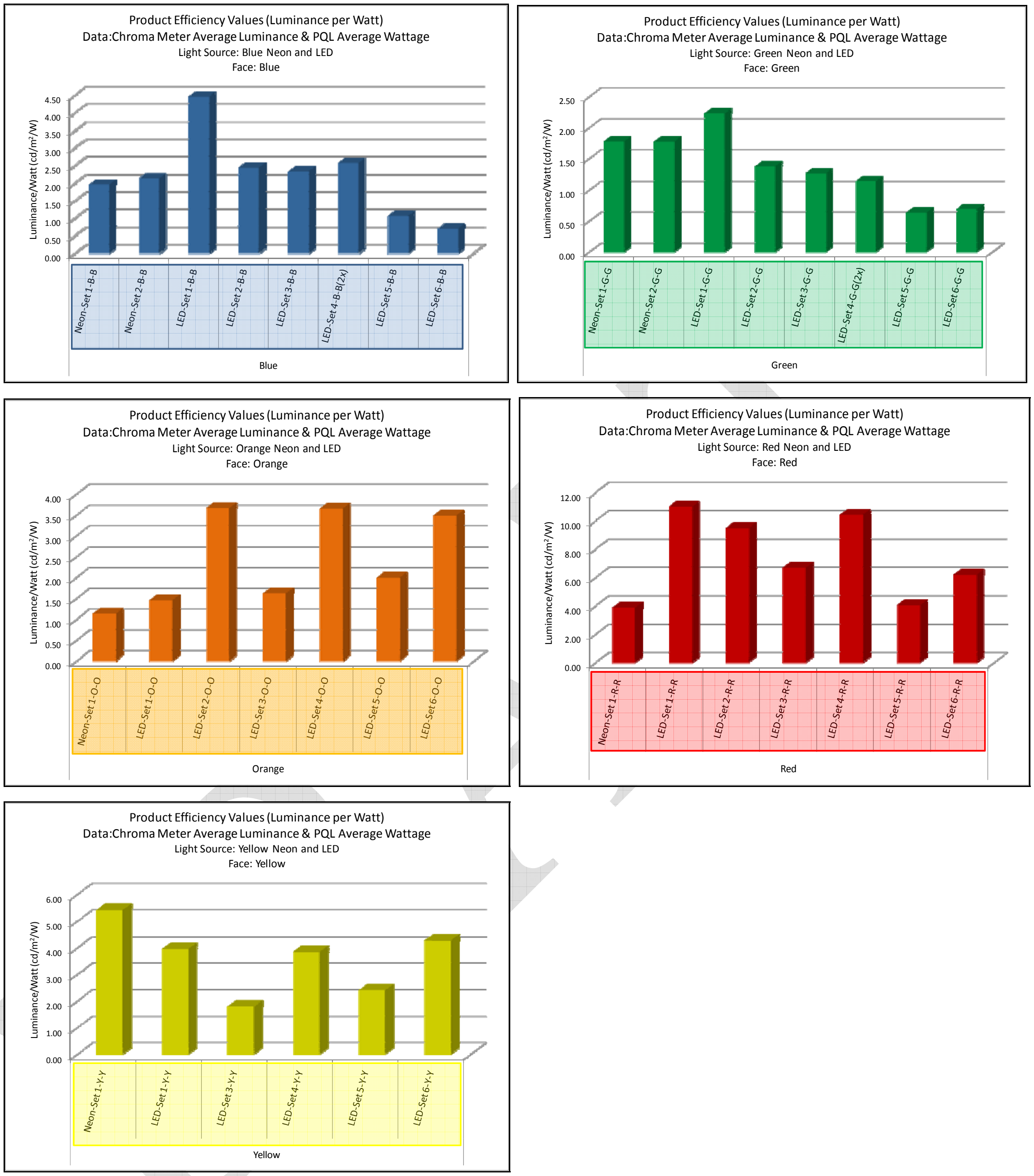

FIGURE 35: PRODUCT EFFICIENCY OF COLOR NEON AND LED WITH MATCHING COLOR FACE

As with the white LED products, when comparing individual products, it is apparent that some color LED products with a colored acrylic face are more efficient than neon products. In all cases with the exception of yellow, one or more LED products was more efficient than the same color neon product. Three yellow LED products approached the efficiency of the one tested yellow neon product.

ENERGY

The California utilities' Energy Efficiency Programs estimate average retail operating hours to be 12 hours per day, 365 days a year. Restaurant and retail compact fluorescent lamp (CFL) operating hours can be used to estimate store open hours, with a reasonable assumption that CFLs are turned off when stores close. Using Restaurant and Retail market sectors in California's Database for Energy Efficiency Resources (DEER),[2] the average hours is also 12 hours per day.

MARKET SECTOR	HOURS/YEAR	HOURS/DAY
Restaurant - Sit-Down	3444	9.4
Restaurant - Fast-Food	6188	17.0
Retail - 3-Story Large	4259	11.7
Retail - Single-Story Large	4368	12.0
Retail – Small	3724	10.2
Average	4396.6	**12.0**

Only restaurant and retail market sectors are used because channel letter signs are used most widely in these market sectors. In some cases, channel letter lighting will follow the same operating hours as the restaurant or store. In other cases, the channel letter sign will run 24 hours a day. Therefore, energy savings was calculated using both 12 and 24 hours per day to provide a savings range.

Using 12 hours per day, the energy savings is calculated as shown in Equation 1.

EQUATION 1: ENERGY SAVINGS

$$Energy\ Savings = (Neon\ Annual\ Energy\ Use) - (LED\ Annual\ Energy\ Use)$$

Where:

$$Neon\ Annual\ Energy\ Use = \frac{(Neon\ Demand) \times (Annual\ Hours)}{(1000\,W/kW)}$$

$$LED\ Annual\ Energy\ Use = \frac{(LED\ Demand) \times (Annual\ Hours)}{(1000\,W/kW)}$$

The following example calculates the energy savings when using a blue light source.

$$Neon\ Annual\ Energy\ Use = \frac{(60.31\,W) \times (4380\ Hours)}{(1000\,W/kW)} = 264.16\,kWh$$

$$LED\ Annual\ Energy\ Use = \frac{(19.49\,W) \times (4380\ Hours)}{(1000\,W/kW)} = 85.37\,kWh$$

$$Energy\ Savings = (264.16\,kWh) - (85.37\,kWh) = 178.79\,kWh$$

Table 8 shows a summary of the energy savings based on the three letter SCE test sign, using white and color neon versus LED lighting for 12 or 24 hours per day (4,380 and 8,760 hours/year, respectively).

TABLE 8: ENERGY SAVINGS FOR LED USE OVER NEON FOR 12 AND 24 HOUR/DAY OPERATION

LED LIGHT SOURCE COLOR	ENERGY SAVINGS (KWH)- 12 HOURS/DAY	ENERGY SAVINGS (KWH)- 24 HOURS/DAY
Red	196.90	393.81
Orange	196.38	392.76
Yellow	165.70	331.40
Green	181.64	363.28
Green(2x)	153.31	306.62
Blue	178.79	357.58
Blue(2x)	136.43	272.87
White	210.21	420.42

It is clear than LED channel letter lighting can provide significant energy savings, especially in applications where it is used 24 hours per day.

CONCLUSION

LED technology for channel letter lighting is promising. Much advancement has been made in recent years with continued advancements still expected. The sample of products assessed here are a good snapshot of products available in 2007. LED technology uses significantly less energy than the traditional neon technology used in many channel letter signs. To maintain sign quality, especially sign brightness, these energy savings need to be considered in conjunction with the product efficiency. On average, LED technology tended to be less efficient when compared to neon, largely due to some products that had very low luminance. However, when looking at individual products, it was clear that some LED products are much better performers than others, and out-perform some of the neon products.

Another consideration when comparing LED to neon technology is the ease of purchase and installation. Neon channel letters must be hand formed to the channel, while LED channel letters come in flexible strips that do not need forming. This allows the user to manipulate the LED channel letter strips to create more luminance, if desired, by increasing the number of LEDs per letter. In these cases, one must weigh the energy consumption, luminance, and cost of the product to ensure it is still a cost-effective measure.

REFERENCES

[i] US Department of Energy, Energy Efficiency and Renewable Energy, *LED Basics*
http://www.netl.doe.gov/ssl/usingLeds/general_illumination_basics_how.htm

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