# Tubular LED Retrofit Report

Submitted to:

*Sacramento Municipal Utility District*

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# 1. Executive Summary

During the past five years, LED technology has experienced tremendous growth and has firmly established itself in the lighting marketplace. LED products are now available for just about every application and great strides have been made in terms of quality and efficacy.

One particularly active category has been tubular LED products (a.k.a. TLEDs). There are literally hundreds of these products available in several different configurations. The performance of tubular LED products has steadily increased and they may soon become a viable option for some applications. However, SMUD and many other electric utilities are not currently providing rebates or incentives for TLED products due to concerns about safety.

These concerns are not necessarily about the TLED products themselves, but rather the installation. Although these products are often marketed as "simple drop-in lamp replacements," there are a lot of things to consider when retrofitting existing fluorescent fixtures to operate TLED lamps.

During the first quarter of 2013, a property management group replaced over one thousand existing linear fluorescent lamps with TLED lamps in a large office building. The installation was completed by experienced electricians stationed at the site. Many valuable insights were obtained during the installation process.

This report is organized into the following sections:

1. Executive Summary
2. General Safety Considerations
3. Project Description & Results
4. Laboratory Tests
5. Appendix

Since there are many types of TLED products, SMUD is currently working with the California Lighting Technology Center (CLTC) and other stakeholders to develop basic guidelines for using TLED products. The guide is scheduled for completion during the first quarter of 2014.

According to RedBird LED, the lamps used in this project were a one-time special order placed by the customer, and do not reflect the performance of RedBird LED's current products which have higher efficacy and better color quality. This is indicative of the ever changing LED field and any study that presents results only can show a snapshot in time of a product at the commencement of the project. Please visit http://www.redbirdled.com/ for the latest product information.

# General Safety Considerations

There are special considerations when retrofitting fluorescent fixtures to operate TLED lamps. Each TLED product and application will have its own set of unique requirements, so care must be exercised to closely follow the lamp manufacturer's instructions. Since installing most TLED products requires rewiring fixtures, anyone interested in installing these products should obtain the services of a qualified electrician.

The product chosen by the customer for this project was RedBird LED's Cardinal Linear Light (a TLED lamp). These lamps include internal power supplies and require the use of non-shunted lamp holders (commonly called lamp sockets or tombstones).

*Figure 1: Fluorescent Lamp with Bi-pin Connectors*

Fluorescent fixtures use ballasts to regulate voltage and electrical current to the lamps and are wired via the lamp sockets. Most four foot T8 and T12 fluorescent lamps connect to the lamp socket via bi-pins as shown in Figure 1. These bi-pins provide electrical connections to the ballast and hold the lamp in place.

When a fixture is wired for single-ended TLED lamps with internal power supplies the ballast is bypassed and line voltage is connected directly to the lamp sockets on one end of the fixture. The lamp sockets on the other end are only used to support the lamp (Figure 2).

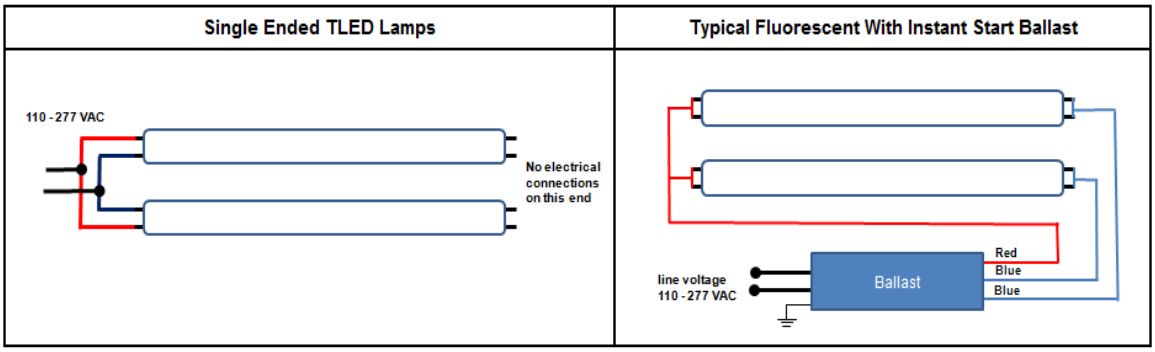



*Figure 2: Fixture Wiring*

Many fluorescent fixtures use instant start ballasts and shunted lamp sockets. The term *shunted* means that both sides of the lamp socket are electrically shorted either internally or via an external wire. When installing TLED lamps with internal power supplies, it is very important to ensure the existing fluorescent lamp sockets are not shunted (Figure 3). Connecting line voltage wires to a shunted socket may result in an electrical short and may cause injury or an electrical fire.

RedBird TLED lamps have a polarity when they are installed, as only one end of the tube is designed for power connection while the pins on the opposite end of the tube are only mechanical supports. Care must be taken during installation to wire the lamps correctly.

If the lamp sockets are the push-in type shown in Figure 4, then all sockets should be replaced with non-shunted, turn-type lamp sockets (Figure 5), as the push-in type may not properly support the extra weight of the TLED lamps.

One of the main safety concerns is that line voltage is applied to the sockets after the retrofit, which is a different voltage than typical ballasted fixture sockets. Some have suggested that the bi-pin sockets used to hold T8 and T12 lamps are not UL Listed for wiring to line voltage (120 to 277V). Others have suggested that connecting line voltage wires to the lamp sockets may present an electrical shock hazard for anyone unfamiliar with TLED retrofit wiring. There have also been concerns expressed about fluorescent lamps being installed in a fixture that has been retrofitted for TLEDs. Although warning labels indicating that the fixture is no longer compatible with fluorescent tubes are typically supplied with the TLEDs and must be installed in the fixture itself to inform future individuals, the lamps sockets will physically accept either type of lamp. SMUD, the CLTC and other stakeholders plan to address these issues in the aforementioned TLED Guide.


*Figure 3: Shunted and Non-shunted Lamp Sockets*

*Figure 4: Push-in Type Lamp Socket*

Finally, if the power disconnects are not part of the existing fixture wiring, then disconnects should be installed for any retrofits that have components such as ballasts or TLEDs (Figure 6).

*Figure 5: Turn Type Lamp Socket*

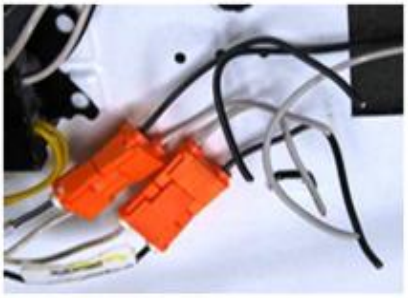


*Figure 6: Incoming Power Disconnects*

# 2. Project Description & Results

This lighting research retrofit project included replacing over one thousand existing linear fluorescent lamps with TLED lamps in a large office building. The installation was completed by completed by experienced electricians who work for the property management company stationed at the site, and included both two and three lamp fluorescent fixtures used for security lighting in common areas. The project scope included:

- Replacing both fluorescent lamps in the two lamp fixtures with TLED lamps and new lamp sockets.

- Replacing the middle fluorescent lamp in three lamp fixtures with TLED lamps and new lamp sockets. Since the middle lamps operate for extended hours and provide security lighting during non-business hours, the customer chose to replace only the middle lamps and leave the two remaining T8 fluorescent lamps.

  Please note: SMUD does not recommend combining TLED and fluorescent lamps within the same fixture since this could create a confusing and potentially hazardous situation. However it should be noted that this project site represents a very controlled environment permanently staffed by experienced electricians, who took several precautions to ensure safety.

- Lab testing the original fixtures with fluorescent lamps and with Redbird LED's Cardinal Linear Lights at the California Lighting Technology Center (CLTC) for total lumens, Watts, efficacy in lumens/Watt (LPW), and light distribution (Sections 4 and 5). The tests were conducted using a three lamp fluorescent fixture and the same model three lamp fixture retrofitted with the RedBird TLED lamps. Results:

  - Average demand savings was 29.2 Watts (34.5%)

  - Fixture efficacy was higher for the TLEDs (81 LPW verses 52 LPW)

  - Color Rendering Index (CRI) was higher for the fluorescent lamps (85 verses 73)

  - The R9 value for the TLEDs was significantly lower than the fluorescents (-19.3 verses 12.5)

  - Total light output for both systems was similar.

Note: the RedBird TLED lamps tested for this report were made based upon a one-time special order and do not reflect the performance of Redbird's current product. Please visit WWW.redbirdled.com for their latest product information.

# 3. Laboratory Tests

Laboratory tests were conducted to compare the performance characteristics of the existing fluorescent fixtures used at the demonstration site versus the same fixtures retrofitted with RedBird LED's Cardinal Linear Lights (tubular LED). The tested fixtures were 2' x 4' recessed ceiling fixtures with three, 32-Watt T8 fluorescent lamps driven by instant start electronic ballasts (ballast factor = 0.88). Testing procedures were performed to assess power input and light output. Laboratory testing was conducted by the California Lighting Technology Center (CLTC) in Davis, CA. The fixtures were tested in an integrating sphere (see Figure 7) to measure total light output and power. The fixtures were also tested in a goniophotometer (see Figure 7 right) which has the additional capability of taking light output measurements at specific angles. A summary of the test results are shown in Table 1, including Watts, total lumens, efficacy (lumens/Watt) and light distribution.

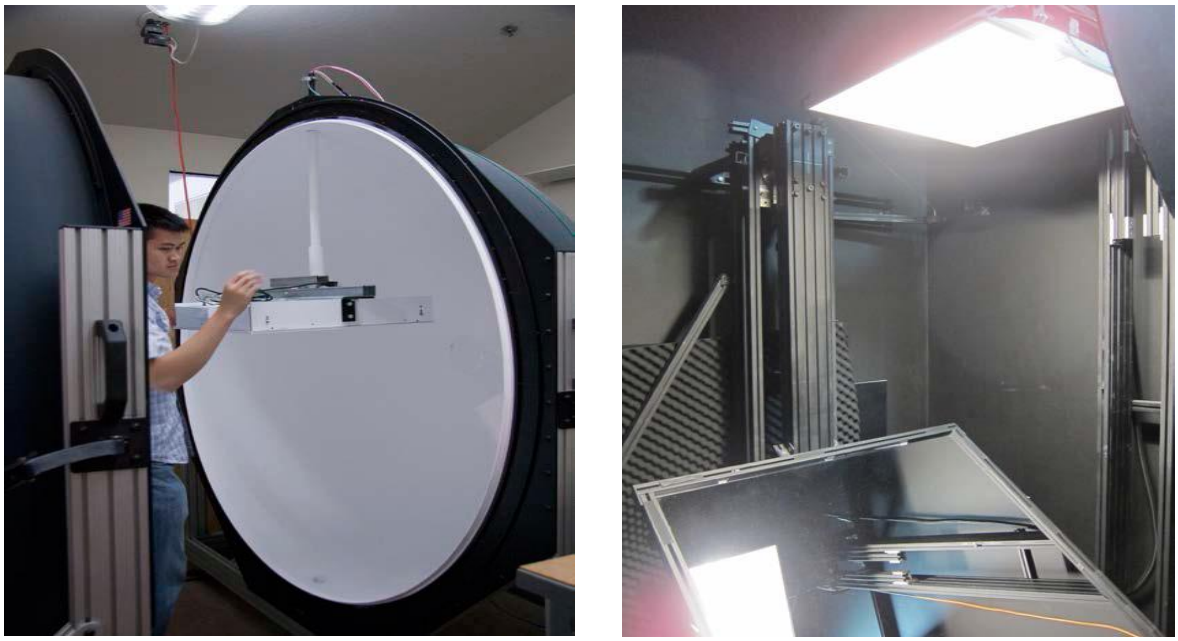


*Figure 7: Integrating Sphere (left) and Goniophotometer (right)*

*Table 1: Summary of Results*

| | | | Integrating Sphere | | | Goniophotometer | | |
|---|---|---|---|---|---|---|---|---|
| | CCT (K) | CRI | Light Output (lumens) | Power (Watts) | Efficacy (lumens/watt) | Light Output (lumens) | Power (Watts) | Efficacy (lumens/watt) |
| Fluorescent | 3,319 | 85.3 | 4,378 | 83.2 | 52.6 | 4,453 | 86.4 | 51.5 |
| RedBird LED | 3,595 | 73.5 | 4,406 | 55.3 | 79.7 | 4,615 | 55.8 | 82.7 |

The following results were obtained from the integrating sphere measurements:

- Power was reduced from 83.2 Watts for the three lamp fluorescent fixture to 55.3 Watts with the same fixture retrofitted with three RedBird TLED lamps. This is a savings of 27.9 Watts or 33.5%.

- Fixture efficacy increased from 52.6 to 79.7 LPW based on measurements, which is a 52% increase.

- Some of the retrofits at the demonstration site were two lamp fixtures and would have an estimated demand savings of 18.6 Watts (33.5%), if both lamps were retrofitted with RedBird TLED lamps.

- Other fixtures at the test site were three lamp fluorescent fixtures where only one lamp was retrofitted with a TLED. The estimated demand savings for this type of fixture would be 9.3 Watts (11.2%).

Average measurements (integrating sphere and goniophotometer):

- The performance of TLED lamps have a 56% higher efficacy than fluorescent lamps based on the average values taken from the two test instruments (81 LPW verses 52 LPW).

- The average demand savings taken from the two sets of instruments are 34.5% or 29.2 Watts for the three lamp fixtures.

The goniophotometer has the additional capability of taking light output measurements (luminous flux in lumens) at specific angle ranges. The results for the fluorescent and RedBird LEDs are presented by zone in Figure 8. The goniophotometer specific angle measurements of luminous intensity are plotted as candela distribution charts in Figure 9 for both the fluorescent lamp fixture and the RedBird LED lamp fixture. This test describes the intensity of light through varying horizontal angles of the vertical plane. LED's have faced challenges with non-homogeneous spacial distribution of light. The distribution produced by the RedBird TLED's compared well to the fluorescent distribution. Additional distribution plots are presented in the Appendix (Section 5).

## Goniophotometer Lumen Summation

Fluorescent

| Zone | Lumens |
|---|---|
| 0-30 | 1,484.78 |
| 0-40 | 2,523.74 |
| 0-60 | 4,177.94 |
| **0-90** | **4,452.61** |

| Zone | Lumens | Percentage |
|---|---|---|
| 0-10 | 175.9 | 3.95% |
| 10-20 | 510.6 | 11.47% |
| 20-30 | 798.3 | 17.93% |
| 30-40 | 1,039.0 | 23.33% |
| 40-50 | 1,024.2 | 23.00% |
| 50-60 | 630.0 | 14.15% |
| 60-70 | 233.0 | 5.23% |
| 70-80 | 35.1 | 0.79% |
| 80-90 | 6.6 | 0.15% |
| **0-90** | **4,452.6** | **100%** |

RedBird LED

| Zone | Lumens |
|---|---|
| 0-30 | 1,455.98 |
| 0-40 | 2,441.63 |
| 0-60 | 4,316.17 |
| **0-90** | **4,615.42** |

| Zone | Lumens | Percentage |
|---|---|---|
| 0-10 | 181.9 | 3.94% |
| 10-20 | 511.2 | 11.08% |
| 20-30 | 762.9 | 16.53% |
| 30-40 | 985.7 | 21.36% |
| 40-50 | 1,162.5 | 25.19% |
| 50-60 | 712.0 | 15.43% |
| 60-70 | 253.7 | 5.50% |
| 70-80 | 39.1 | 0.85% |
| 80-90 | 6.4 | 0.14% |
| **0-90** | **4,615.4** | **100%** |

*Figure 8: Goniophotometer Lumen Summation*

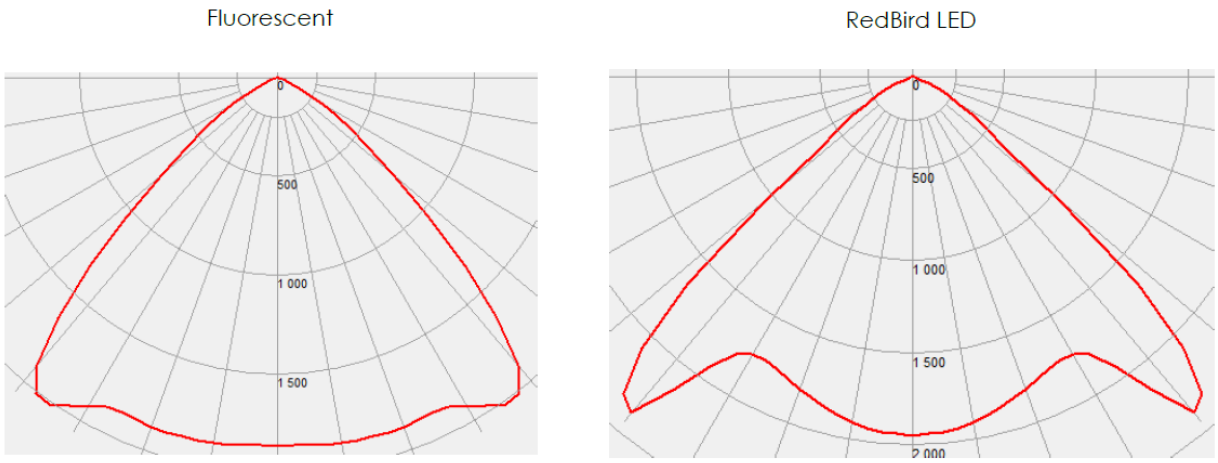



*Figure 9: Goniophotometer Candela Distribution*

The correlated color temperature (CCT) is the surface temperature of the electromagnetic radiation emitted from an ideal black body. The scale ranges from candle light reds at 1,700K up to clear sky blues at 27,000K. The fluorescent and RedBird LED values fall into the range of yellow-whites (Figure 10). These values are very similar on the emitted light scale. The CCT for the fluorescent lamps is 3,319 °K and the RedBird LEDs are 3,595 °K.

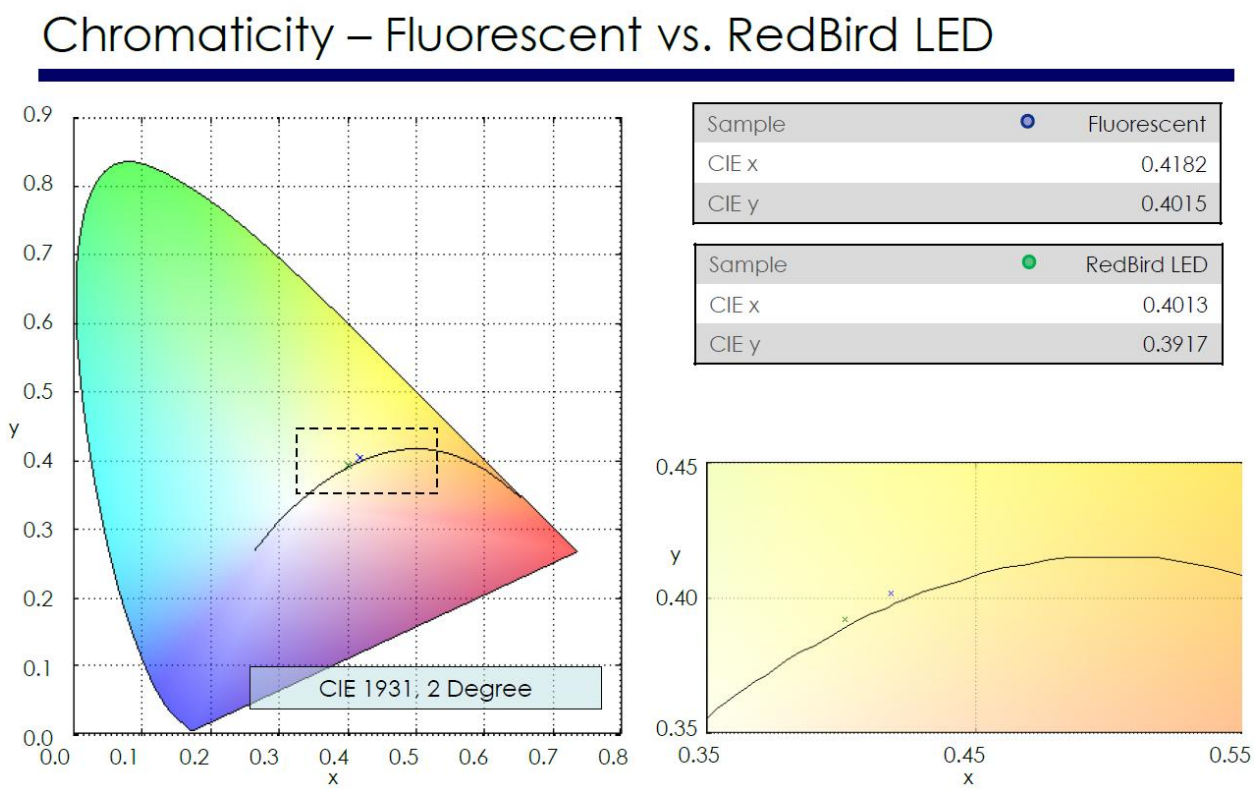



*Figure 10: Chromaticity*

The color rendering index (CRI) measures how well a color renders, meaning how close a color appears to its standardized reference, under the tested light source. The test is performed with 14 standardized color test samples for comparison (Figure 11). The light quality is represented as a number up to 100 indicating the highest level of rendering. The fluorescent lamps have on average better rendering capabilities than the RedBird TLED. The average CRI for the fluorescent lamps was 85.3 while the average CRI for the RedBird LEDs was 73.5. The Redbird TLED lamps have particularly low rendering values for the red R9 sample because LEDs perform more predominantly in the blue sections of the spectrum.

Note: the RedBird TLED lamps tested for this report were made based upon a one-time special order and do not reflect the performance of Redbird's current product. Please visit WWW.redbirdled.com for their latest product information.

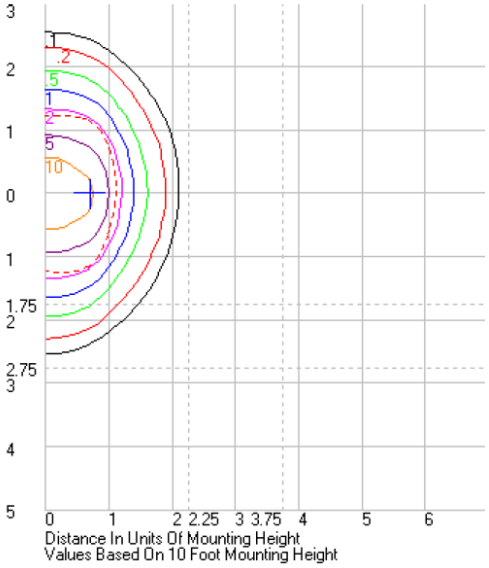
| | Fluorescent | RedBird LED |
|---|---|---|
| **R1** | 98.9 | 70.5 |
| **R2** | 96.4 | 80.9 |
| **R3** | 57.6 | 88.3 |
| **R4** | 91.7 | 70.9 |
| **R5** | 89.0 | 69.2 |
| **R6** | 84.2 | 71.9 |
| **R7** | 91.3 | 82.4 |
| **R8** | 73.0 | 53.8 |
| **R9** | 12.5 | -19.3 |
| **R10** | 56.5 | 53.6 |
| **R11** | 76.7 | 64.8 |
| **R12** | 60.1 | 43.7 |
| **R13** | 95.9 | 72.2 |
| **R14** | 70.7 | 93.1 |
| **Ra** | **85.3** | **73.5** |

*Figure 11: Color Rendering Index*

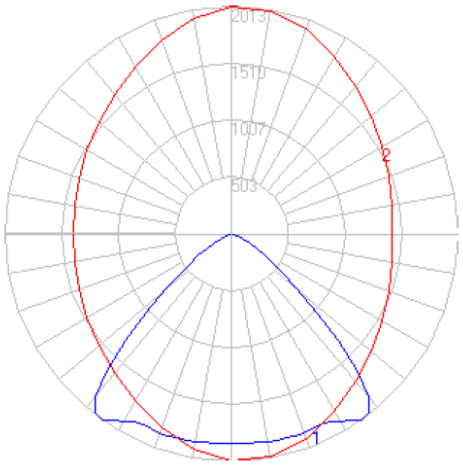
# 4. Appendix

This section includes additional goniophotometer tests results.

## Goniophotometer Characterization – Fluorescent



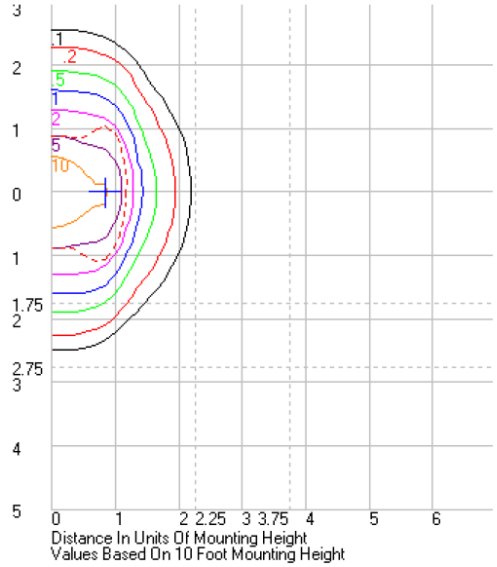

Red Dash: ½ Max Candela
Blue Cross: Max Candela Point



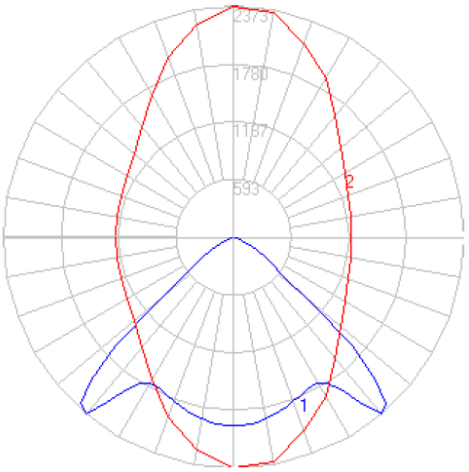

Vertical Plane Through Horizontal Angles:
Blue: 90˚ - 270˚ (Through Max Candela)

Horizontal Cone Through Vertical Angle:
Red: 35˚ (Through Max Candela)

# Goniophotometer Characterization – RedBird LED




Red Dash: ½ Max Candela
Blue Cross: Max Candela Point




Vertical Plane Through Horizontal Angles:
Blue: 90˚ - 270˚ (Through Max Candela)

Horizontal Cone Through Vertical Angle:
Red: 40˚ (Through Max Candela)

The measured spectral power distribution for both lamp types is presented below.

## Spectral Power Distribution – Fluorescent vs. RedBird LED