A Systematic Approach for Evaluating LED Street Light Fixtures

By Blake Redfield

LED street lights are gaining popularity throughout the US and the world. Numerous companies have offered LED street lights for several years and have had reasonable success in various lighting projects. However, due to the high costs of LED street lights and the marginal energy savings that they currently provide, LED street lights must provide other benefits including reduced maintenance, better light color rendering, better light uniformity, lower light loss factors and other areas that help improve performance and the bottom line.

A recipient of ARRA funding, the City of St. Cloud, Minnesota had the opportunity to fund several projects including the installation of LED street lighting. Upon completion of the primary ARRA projects (new heating systems, repairs to an atrium, an electrical generator, etc.) the remaining funds could be used for decorative, LED acorn fixtures. The city had two corridors of 20 year old acorn fixtures in a residential neighborhood that needed replacement; the fixtures were of poor quality when installed and have required extensive maintenance over the years. Also, the median lighting along one of the corridors had originally been equipped with dual light fixtures that required twice the maintenance as single units. The double fixtures were reduced to a single fixture.

After the announcement of the proposed LED lighting project, numerous lighting companies began bringing in their LED lighting products with the potential of a significant LED light fixture sale to the City of St. Cloud. Each company provided their information of why their fixture was superior to their competitor’s and it appeared that new lighting companies were popping up every week to have a chance at the project. The question became, “how does one evaluate the various fixtures and provide the best possible unit for the city?” Not only did we want a fixture that provided good quality light, we wanted a street light fixture that would be reasonable to maintain and operate for the long term as well.

In order to get the best light fixture for our requirements, St. Cloud’s Traffic Services developed a series of tests and comparison methods that provide an objective method for comparing decorative LED light fixtures. The first part of the testing included a method that would provide the light output of the fixtures and the ability to compare data with other fixtures. Some cities have placed street light fixtures along roadways and have input from the residents and what they think about the various fixtures. This method is okay but not overly objective or scientific. This type of evaluation is also quite time consuming. However, The City of St. Cloud did not have the time to do this type of evaluation which is still quite a subjective method of testing. Rather than involving input from residents, Traffic Services developed a light output test deck where 64 measurements of light are taken in a controlled environment with virtually no chance of outside influences or variables that would influence the test results.

Test Deck. The test deck is quite a simple device being constructed of two sheets of ¾” plywood creating an eight foot by eight foot deck and built to table height. The deck was painted flat black to minimize light reflection. There are 64 alignment holes spaced one foot apart that have been cut into the deck that allow a light meter sensor to be quickly placed and have consistent measurements. The light fixture is placed on an arm which is supported by a pallet jack that allows the fixture to be aligned both vertically and horizontally.

Test deck with LED acorn fixture centered over the unit. (Note various other acorn fixtures in the background) (Additional background lighting was used for the photograph)

After building the test deck, Traffic Services purchased a very high quality light meter with some unique features. The light meter is a Konica Minolta model CL-200 Chroma Meter. The unique features of this meter include a detachable light sensor that can be mounted on a remote surface and connected to the main body.

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of the meter via a standard Ethernet cable. The light meter can also be daisy-chained for up to 16 light sensor units for multiple inputs. Due to the price of the sensors, Traffic Services opted out of the multi-sensor idea and decided to move the sensor from one station to the next on the test deck. The second important feature is that the light meter can read the color temperature of the LED light which is critical in making sure the end user receives the color temperature of LED light that has been specified.

**Test Explanation.** The test deck represents the light output of the test fixture with concentrated light at just 2.5 feet above the test deck. The light is measured at 64 points on the test deck level. With a fixture mounting height of 15 feet as shown below, the test deck is simulating light that would cover approximately 1296 square feet.

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With the high directionality of LED light fixtures, 49 square feet of the test deck is a fairly good representation of the fixture light output that can be projected to 1296 square feet if the fixture were mounted at 15 feet. Another nice thing about measuring light on the test deck is the high signal to noise ratio. Because of the high levels of light being measured and the controlled environment, there is much less chance of measurement errors than trying to read measurements on the roadway where moonlight, snow reflection, headlights, neighborhood lights and other light or reflective sources can have impacts on very low levels of street light.

**Light Color Temperature.** As a residential neighborhood LED lighting project, a warmer color temperature was required for the project. As with the light level readings at the 64 stations on the test deck, color temperature readings are also recorded at each of the measurement points. The Chroma Meter has a very nice display that indicates both the light level and color temperature simultaneously. In the photo to the left, the meter is displaying the light level in footcandles and the color temperature in degrees Kelvin. LED lighting tends to be very blue in nature and in order to get to a whiter light, the LEDs are doped with coloring agents to bring them into the white lighting spectrum. Most street lighting LED light sources tend to provide light in the 4000 – 5000K range. However, to provide the warmer feel in the residential neighborhood a 3500K LED standard was chosen and Traffic Services wanted to verify that is what it received. The light temperature calculations will be discussed later in this article.

**Lighting Test Preparation.** Each light fixture was placed on the support arm, aligned to vertical nadir, rotationally aligned, centered on the test deck and measured to 2.5 feet from the test deck to the top of the lens. All light sources in the area are extinguished. The test deck is inspected for foreign objects or paint degradation. The Chroma Meter is set up and inspected to make sure all equipment is functioning properly.

**Recording and Compiling Data.** The test deck has a small white sticker with an address of A-1, A-2, etc. for each test point. The Chroma Meter receiver placed on the shoe is moved from one station to the next with both the light levels and color temperature being recorded throughout the test process. The test person stands back as far from the receiver as possible to minimize any reflections back to the receiver unit. When the test deck readings are complete, eight light measurements are taken around the perimeter of the test deck to determine the 80 degree and 90 degree light levels from the top of the lens. These values will determine the fixture’s ability to minimize light trespass and meet dark sky standards. Upon completion of the readings from the test deck stations, all data values are placed in a computerized spreadsheet where the values can be utilized for reports and graphing. Upon complet-
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Light Evaluations. Several lighting factors were reviewed and formulas developed in order to provide a fair and consistent evaluation process for each light fixture that would provide Traffic Services with an objective evaluation process. Most of the evaluations are simple mathematical functions that generate a score for various categories of light quality.

Light Uniformity Score. This number indicates the uniformity of the light on the test deck. The average of the 64 measurements was determined and divided by the minimal light level of the 64 measurements. Once this ratio was determined, the value is subtracted from 10. The maximums and minimums are 10 and 0. Integers are used to keep the values as whole numbers.

Uniformity Score = Integer(10 - (Average of 64 measurements/Minimum of 64 measurements))

Light Cut-Off Score. In order to assure that the light fixture was providing adequate cut-off between 80 degrees and 90 degrees, light measurements were taken along the edges of the test deck at the 80 and 90 degree points on all four sides of the test deck. The values of both were averaged and then a ratio betwen the two was established for a score value. A maximum score of 5 was allowed in this category. Integers are used to keep the values as whole numbers.

Light Cut-off Score = Integer(Average light value at 80 degree/Average light value of the 90 degrees)

Light Output Score. The output score is a simple matter of summing the total light output values of the 64 measurement points and dividing by 100. This value provides a simple raw light output value.

Light Output Score = Integer(Sum of the 64 fc measurements/100)

Spreadsheet Evaluation. There were several things that St. Cloud Traffic Services wanted to evaluate when reviewing various LED light fixtures beyond the light levels and color temperature. Each LED light fixture was torn down as far as they could be disassembled by the electrical department and evaluated on a scale from 1 to 5 on several factors including: workmanship, quality of materials, surface finish, ease of electrical equipment replacement, ease of diffuser replacement, product standards (i.e. metric or SAE), structural integrity, warranty, type of LED driver, LED components, LED thermal management and origin of production. Each of these items was factored into the final evaluation of each fixture.

The lighting data became the complex portion of the evaluation.
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**Light Color Standard Deviation Score.** The light color standard deviation value helps determine the uniformity of the light color temperature uniformity. A good LED light source should have quite similar color temperature values throughout its light output areas.

Light Color Standard Deviation Score = \( \text{Integer}\left(\frac{1000 - \text{Color Standard Deviation}}{100}\right) \)

**Color Temperature Score.** Wanting 3500K color temperature for a residential street lighting, the scoring system provides higher score values the closer an LED light source. The formula may need to be adjusted if other color temperature values are wanted.

Color Temperature Score = \( \text{Integer}\left(\frac{6000 - \text{Average Color}}{250}\right) \)

**Light Efficacy Score.** LED light efficacies are really the most important part of LED light fixtures and the value should be weighted to this fact. The efficacy that is measured is simply the total number of foot-candles from the test deck divided by the AC input wattage required to operate the LED fixture. It is important to measure the AC input wattage and not the power output of the driver as there may be losses within the driver.

Light Efficacy Score = \( \frac{\text{Total number of footcandles}}{\text{AC input wattage}} \)

**Thermal Management.** Although not a separate scored item, thermal management became a major consideration in the choice of light fixture. Heat will be the greatest reducer of life to an LED fixture and companies have come up with several methods to handle the heat associated with solid state devices. Traffic Services chose an LED light fixture with a cast aluminum top with the LEDs attached directly to it to transfer heat to the outside of the fixture.

**Total Light Fixture Score.** The final score of each LED light fixture is the total of the various aspects of the fixture and light output.

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\text{TotalFixtureScore} = \text{light fixture quality score} + \text{light uniformity score} + \text{cut-off score} + \text{light output score} + \text{light color standard deviation score} + \text{light color temperature score} + \text{light efficacy score}
\]

**Graphics.** In order to get a better visual idea of the output and uniformity of the individual light fixtures, various charts were developed to display light outputs on the test deck and projected lighting levels at various fixture’s height. Microsoft’s Excel has excellent chart capabilities and can provide the user with visual renderings that are easy to understand and show features that are difficult to comprehend by just looking at groups of numbers. Initially the two dimensional test deck charts helped show uniformity and various lighting levels. However, it was soon discovered that three dimensional renderings had some great information that was not as obvious with the two dimensional graphics. The chart below shows good uniformity for a Type V light distribution pattern. However, unless one looks at the legend it is difficult to determine if values are increasing or decreasing.

The two dimensional light distribution pattern above is excellent for verifying and viewing uniformity and the proper distribution type. However, it is difficult to determine which level is greater or smaller than the previous.

The three dimensional light distribution pattern above is excellent for viewing the true shape of the light distribution and is easy to identify the fact that there is somewhat of a light loss near the center of the fixture. All fixtures have some loss near the center. This fixture has minimal losses compared to others. This fixture is as close to a positive model for light distribution that was noted during the testing process.
Comparing LED light fixtures. After running tests on numerous light fixtures, it became very obvious that there was a great deal of difference from one light fixture to the next. Light outputs, efficacies, shadowing, light uniformity, quality of the fixtures and many of the other factors varied greatly. The three dimensional light distribution patterns on charts quickly gained value in determining what type of light outputs were being generated by the various light fixtures that were tested. A problem that started coming up with several fixtures was shadow areas near the center of the light patterns.

Some light patterns were rather unusual and uneven. The pattern to the right is from a light fixture with a Type V distribution but looks closer to a Type III distribution with the higher value on the one side than its opposing side.
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Projections. Using the rule of inverse squares, one can project light levels with fixtures mounted at various heights. This fixture’s output was calculated for a twelve foot mounting height. Although not as good of a way of determining projections as using photometric programs and the appropriate ies files, there would be some light level output available for the user. One must recalculate the grid pattern widths to coincide with the elevation of the light fixture.

Conclusion. The test deck and evaluation process provided the City of St. Cloud Traffic Services with invaluable information on the quality and lighting capabilities of the various LED light fixtures that were tested. It also provided the city with much more objective data and comparisons that are difficult to get from the manufacturers. The City of St. Cloud did finally settle on a particular fixture and installed 83 new LED acorns in December of 2010. There will be 50 additional LED acorn fixtures being installed in the spring of 2011. The test deck and methodology used is not intended to provide ies quality photometrics or provide absolute photometry. However, the methodology did provide a way of making sure each LED light fixture was tested in the exact same manner and that there was no exaggeration of light output or efficacy of the fixture. It also provided Traffic Services with proof of correct color temperatures and light distribution type for the fixtures. The test method also indicated which light fixtures will cast shadows around a light pole base which is difficult to determine with ies data alone. The LED street light project has been a success with excellent light levels, uniformity, excellent color temperature and reduced electrical costs. The high quality fixture chosen for the project should provide minimal maintenance for many years in the future.

About the author. Blake Redfield has been involved with traffic engineering and lighting for more than 25 years. Blake holds multiple IMSA certifications and has had numerous articles published in the IMSA Journal and other publications throughout the years. Blake is currently the Traffic Systems Manager for the City of St. Cloud, Minnesota. For further information on this topic, email Blake at: blake.redfield@ci.stcloud.mn.us

(Endnotes)

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