City of Raleigh
Municipal Garage LED Lighting Pilot Project

Raleigh, NC
May 24, 2007

Introduction

Through a series of discussions about LED lighting and energy efficiency, the City of Raleigh, NC (The City) and Cree, Inc. (Cree) developed a plan to jointly test, evaluate and subsequently deploy LED lighting solutions within the City infrastructure. This joint initiative, launched as the LED City™ initiative on February 12, 2007, will evaluate the deployment of LED lighting across a number of City lighting applications.

Key to the LED City initiative is the identification of several pilot LED lighting installations to explore the ease of implementation, the public's reception of the lights, the costs and the benefits of LED lighting. The first pilot application identified and deployed is low bay lighting in the municipal garage building, located behind the municipal building in downtown Raleigh.

This report will document the detailed information about this installation, as well as the initial results of the pilot evaluation, including the energy savings, projected maintenance savings, quality of light and the business case analysis.

Existing Municipal Garage Lighting

The municipal garage, built in 1984, is a four level structure, with the first level located underground. A photo of the garage building is shown in Figure 1 below. The installed garage lighting is typical of buildings constructed during that period – High-Pressure Sodium (HPS) fixtures.

Figure 1

Levels one through three of the garage are equipped with low bay HPS fixtures containing 100-watt bulbs and associated ballasts. The ceiling mounting height for the fixtures is 8 feet, and the fixtures are typically spaced 20 feet apart. Over the vehicle and pedestrian entrance and exit areas, additional light fixtures are mounted with 10 foot spacing.

Levels one and two of the garage are used by the City police department and the City services departments respectively. Levels three and four are used by both City employees and by the public. We choose level three for the LED pilot since this level contained lights that burn twenty-four hours a

day, and it is used by the public. The specific location and spacing of the light units for level three is shown in Figure 2 below. The top or fourth level is lit with pole-mounted 150-watt HPS units.

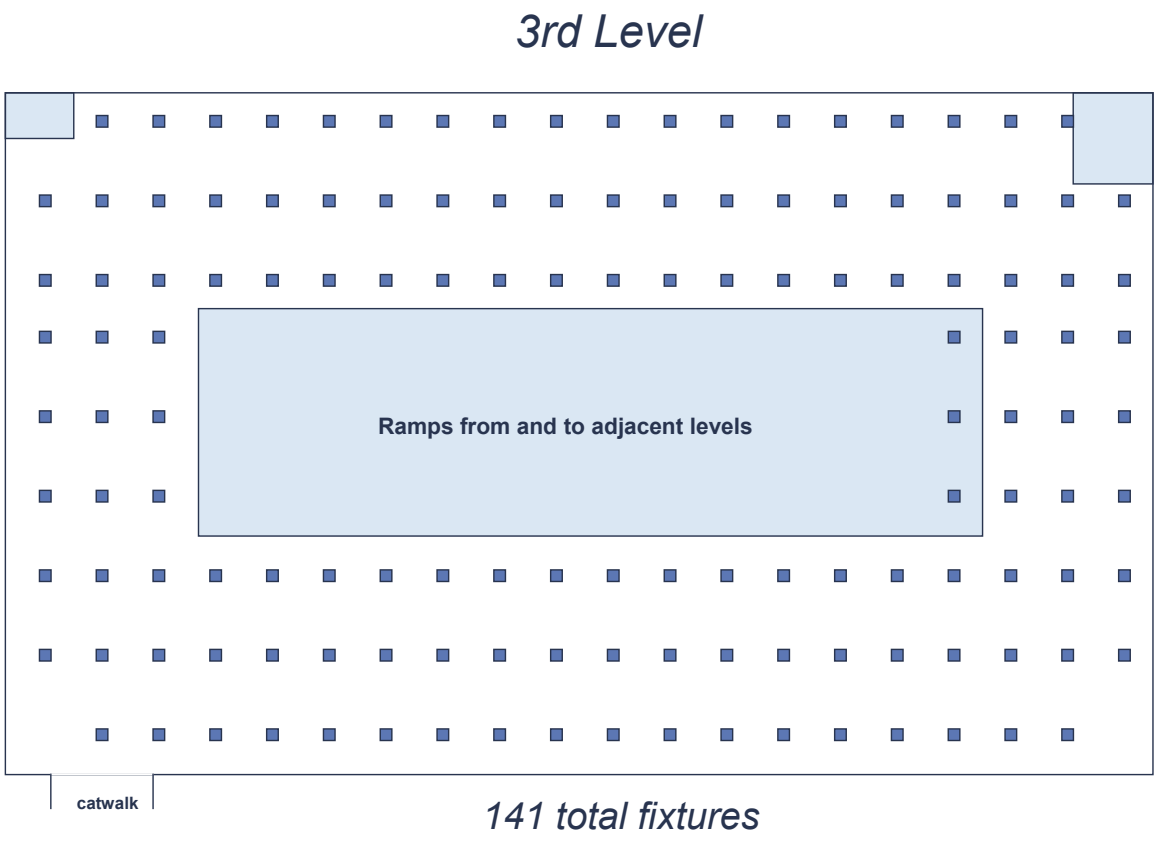

Figure 2

LED Lighting Solution

Level three of the garage originally contained 141 HPS low bay light fixtures, excluding the ramps entering and exiting this level. These fixtures have been in-place since the garage was constructed. An example of the HPS fixtures installed is shown in Figure 3.

Figure 3

We replaced each HPS fixture with an LED low bay light fixture supplied by Lighting Science Group Corporation (LSG) www.lsgc.com. This fixture was chosen based on being a one-for-one, plug-compatible replacement for the existing HPS fixtures and its ready availability. A photo of an example of the LSG fixture is shown in Figure 4.

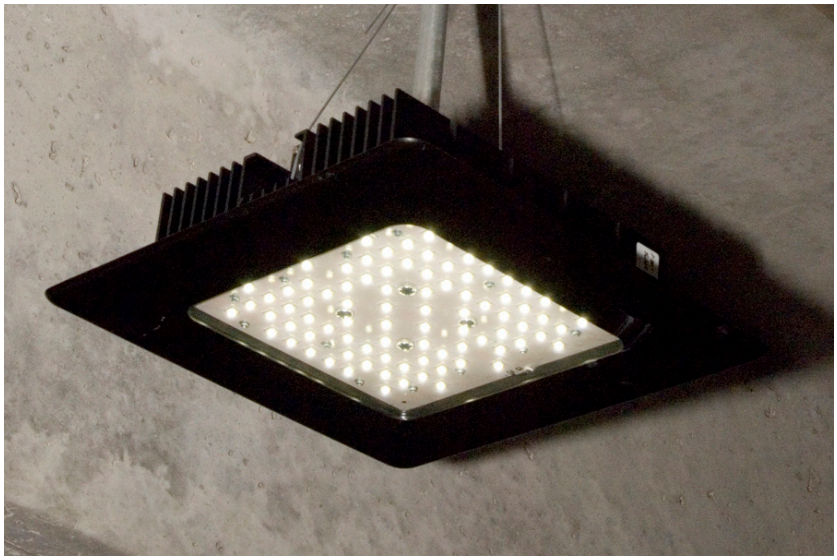

Figure 4

Specifications, a photometric report and IES files for the LSG low bay fixture are available at www.lsgc.com/led_lighting.htm. Please direct all inquiries regarding this fixture to Lighting Science Group, Corp.

It is important to note that due to the rapid advance of LED lamp technology, new, higher-performance LEDs have recently been introduced that provide significantly higher brightness and efficiency than the LEDs used in the fixtures installed for this initial pilot. For information on the latest Cree XLamp® LEDs, please visit www.cree.com/xlamp.

Amtech Lighting Services, www.abm.com/ilwwcm/connect/ABM/Home/Lighting/, installed the LED fixtures over the course of a week. They performed the installation in sections after working hours to minimize the disruption of normal garage operations. Each fixture is attached to the electrical junction boxes by a metal conduit, as shown in Figure 4 above. In addition, to provide additional support and stability, two steel cables are attached on opposing sides of the fixture, and are anchored to the garage ceiling.

The LED fixtures contain a solid-state power supply that auto-adapts to input voltages from 100-to-300 watts AC. The power supply connects to the metal conduit and wiring, and the fixture itself attaches to the power supply via a sliding channel attachment with an electrical plug connector from the power supply. This allows for easy removal and replacement if necessary.

The installation was completed on January 11, 2007.

Municipal Garage Pilot Results

Energy Usage and Savings

LEDs are semiconductor devices that are experiencing very rapid improvements in performance, both brightness and efficiency. Due to this rapid progress, LEDs now surpass the efficiency of most conventional light sources. In addition, the construction of packaged LED lamps allows light fixture manufacturers to optimize the light emitted by the devices in the fixture thereby increasing the efficiency of the fixture itself, and delivering more “useful” lumens to the application.

This inherent efficiency allows LED lighting solutions to provide significant energy savings in many lighting applications, such as the garage installation described above. To validate the energy savings provided by the municipal garage LED lighting installation, the City of Raleigh and Cree enlisted the participation of the local Raleigh electrical utility, Progress Energy, www.progress-energy.com.

Progress Energy measured the total load of the HPS fixtures, at steady-state, using a Metrosonics POA9 Plus load meter. The steady-state load of the HPS fixtures was 120 watts each. They then measured the load of the LSG LED fixtures, and determined a steady-state load of 70 watts each. This shows a forty percent (40%) decrease in the power consumption of the fixtures in the municipal garage.

In addition, as shown in the load chart below, the power factor improved dramatically by using the solid-state power supplies in the LED fixtures.

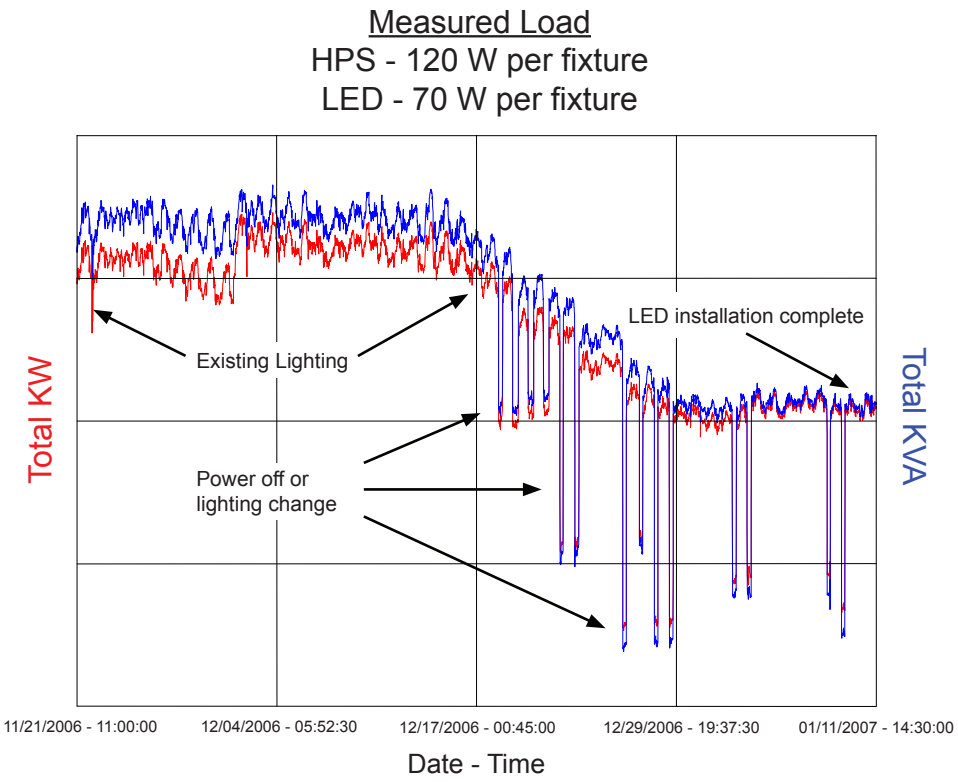

Figure 5

Based on Progress Energy’s measurements, each LED fixture is saving fifty watts (50W) of electricity over the HPS fixture it replaced. As described earlier, level three of the garage contains 141 fixtures, and assuming twenty-four-hour-a-day operation, this would result in approximately 170 kilowatt-hours (KWh) of savings per day.

The municipal garage, however, employs a photocell sensor and associated controls to turn a portion of the lights off during daylight hours. This reduces the power consumption during the day when ambient daylight reduces the need for the garage lights. This type of control is applicable for aboveground garage structures, but cannot be used in the underground portions of the garages.

Of the 141 fixtures in the garage, 69 fixtures are controlled via the photocell sensor, and hence operate an average of 12 hours-a-day year-round. Therefore, the projected reduction in electricity usage for level 3 of the garage is approximately 128 kWh per day, or 46,720 kWh per year.

As noted earlier, the performance of the LED technology employed in the LED fixtures used in this trial has been surpassed by LEDs introduced in the past six months. In fact, the efficiency of the current generation of Cree LEDs is over 75% higher than the LEDs used for the municipal garage installation. This improved efficiency and performance can help to deliver electrical savings of approximately 70% over the HPS fixtures originally installed in the garage.

Therefore, LED fixtures containing the current generation of LED technology could deliver electricity savings for level 3 of the municipal garage of up to 82,000 kWh per year.

Maintenance Savings

LEDs have very long service lifetimes, and are projected to maintain over 70% lumen maintenance after 50,000 hours of service. In a twenty-four hour-a-day application, this translates to 5.7 years, and in a twelve hour-a-day application, such as with the photocell control, it translates to 11.4 years. Moreover, after 100,000 hours of service, lumen maintenance is projected to be approximately 50%. This translates to 11.4 years assuming twenty-four hour-a-day operation and 22.8 years for twelve hour-a-day operation.

Due to the long service life, the use of LED fixtures can eliminate the need for bulb replacements for the service life of the fixture thereby saving not only the cost of the bulbs, but also the cost of the labor required to change them. Current solid-state power supplies are designed to last the life of the fixture. This also eliminates the equipment and labor costs of replacing ballasts, as is required with traditional fixtures.

LEDs, unlike many traditional light sources, are very tolerant of ambient temperature variations, vibrations and on/off cycles. In parking garage applications, traditional light sources often fail due to the inhospitable environment, necessitating frequent replacements.

Also, since LED light fixtures are not designed to allow traditional bulb replacement, the fixtures can be tightly sealed thereby preventing the accumulation of dirt, insects and moisture on the inside of the diffuser or lens cover. This serves to essentially eliminate the need for time-consuming disassembly and cleaning of the fixture lens as is usually required with traditional lighting fixtures. The only cleaning that may be required, depending upon the environment, is to clean the outside of the lens or diffuser.

From these observations, the City of Raleigh has estimated that they can save approximately 95% of the annual lighting maintenance budget allocated to this level of the parking garage. The labor savings from this reduction in required maintenance frees City employees to address other critical needs within the City.

Quality of Light

In addition to the expected savings from the reduction in electricity consumption and maintenance, an important consideration for the City is the perception of the quality of light by the garage users. LEDs, unlike traditional light sources, can be produced in a wide variety of colors and levels of brightness. Of particular importance to many lighting applications, including the municipal garage, are the delivered lumen output, the correlated color temperature (CCT) and the color-rendering index (CRI) of the lights. These measurements, in simple terms, quantify the amount of light delivered, the color of the light and the ability of the light to show the colors of objects.

HPS light fixtures, although relatively efficient, have a very low CCT (approximately 2100 K) and a low CRI (approximately 20), which results in the familiar yellow-orange light we're accustomed to from many outdoor lighting installations. The LED fixtures, used in this application, deliver a CCT of approximately 5500 and a CRI of approximately 80. The results of the LED lighting installation are most visible via the "before" and "after" photographs, as shown in Figures 6 and 7 below.

Figure 6

Figure 7

Also important, is the amount of light delivered in the application. To measure the delivered light output, we again enlisted the participation of Progress Energy. This time, members of Progress Energy's lighting solutions group performed light level measurements, using a Minolta Illuminance Meter Model T1. Measurements were taken prior to the installation of the LED light fixtures, and then again after the installation.

To help ensure good coverage of the garage, we selected twenty-five locations around the garage where we performed surface-level horizontal and five-foot height vertical measurement of the light levels. The vertical measurements were taken in the same four directions at each point. The locations of the measurements are shown in Figure 8.

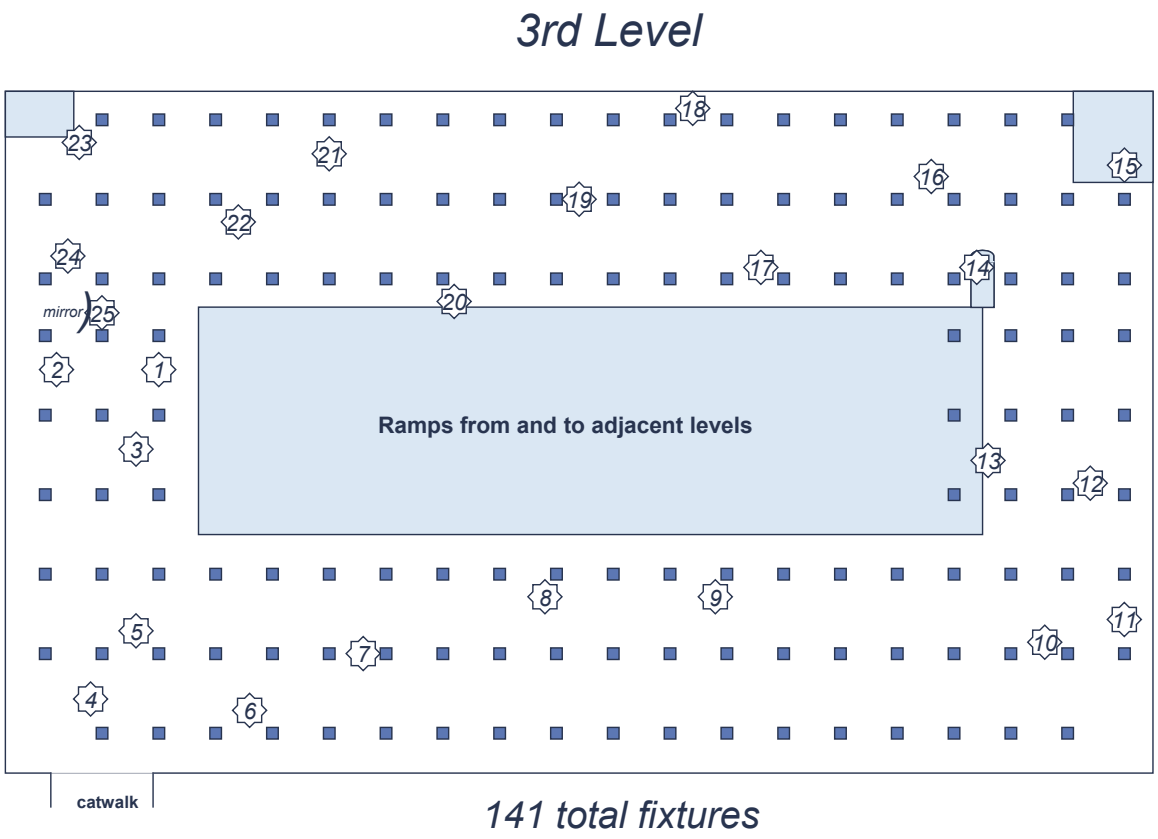

Figure 8

The results of the light level measurements before and after the installation of the LED light fixtures showed approximately an 11% decrease in average foot-candles and effectively unchanged min/max ratios – remaining well above the IES recommended levels for parking garages. However, due to the much whiter color of the light and the vastly improved CRI, the perceived light levels are much greater. See the survey results that follow for more on customer perceptions.

Public Safety and Security

To gauge the impact of the higher-quality lighting on public safety and security monitoring, we captured images from color security cameras installed by Diversified Systems, Inc. of Raleigh, NC. The first set of video images, from December, 2006, were taken before the installation of the LED fixtures and the second set of video images, from January, 2007, were taken after the installation of the LED fixtures. Risk Management Associates, also of Raleigh www.rmasecurity.com, then analyzed the images to assess the difference in image quality resulting from installing the LED lighting.

Excerpts from RMA's analysis include:

"When the video is compared, the difference is immediately noticeable."

"The video from December shows parking areas well lit with the usual yellow/orange hue cast from the lights. … it appears that some areas show adequate detail while others look to be in shadow. .. leaves shadow areas where individuals can hide and lay in wait to perpetuate criminal activity. The additional shadows can also give a person a feeling of a lack of safety."

“When viewing the video from January, 2007 with the new lighting, the areas that appeared to be in shadow now seem to be less so….also looks like a greater level of detail is now visible.”

“Identifying the true color of the vehicles parked at longer distances is now simpler. The lighting appears more evenly distributed and brighter without creating additional glare or blooming that is associated with increasing the amount of incandescent lighting.”

“The new lighting is far more effective over the original sodium vapor lights. … What this means is there should be sufficient lighting to positively identify a face and read body language at a distance of 30 feet.”

Garage User Survey

We engaged Mindwave Research, Inc. of Austin, Texas, a leading technology market research firm, www.mindwaveresearch.com to perform surveys of the garage customers both before the lighting conversion and afterwards. This survey measured overall satisfaction with the parking garage, opinions about garage cleanliness, lighting quality and feelings of safety, as well as opinions about parking space size and quantities, maneuverability and entrances and exits.

The findings from the surveys indicated a very significant improvement in the customer’s feelings of safety, opinions about the lighting quality and satisfaction with the overall garage. Interestingly, opinions about the garage cleanliness, maneuverability and parking spaces also improved.

Details from the survey are below.

Screening Criteria

To qualify to participate in the study, all respondents had to meet the following criteria:

- Respondents must be 18 years or older
- Surveyed respondents must park on the flat area of Level 3 of the parking garage
- Those parking on the ramps leading to and from Level 3 are not to be surveyed

Methodology

- **Independent survey commissioned by CREE and executed by Mindwave Research**
- **Survey administered in a Raleigh, NC municipal parking garage**
- **One-page, self-administered survey taken upon entry/exit to the garage**
  - Identical 2-3 minute survey delivered to respondents pre- and post-installation
  - Administered via intercept interviews
- **Field Dates:**
  - Pre-Installation: November 13 – 17, 2006
  - Post-Installation: February 5 – 8, 2007
- **400 total completed qualified interviews:**
  - 200 pre-installation
  - 200 post-installation

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CREE Municipal Parking Survey Results

CREE LED Light

Key Findings and Recommendations

Key Findings

- Perceptions of the lighting quality improved three-fold post-installation
- Overall satisfaction with the parking facility doubled with the installation of the LED lighting solution
- Both males and females felt significantly safer after the lighting was changed
- Ratings on maneuverability, cleanliness, and number of available parking spaces also improved significantly after the installation of LED lighting

Recommendations

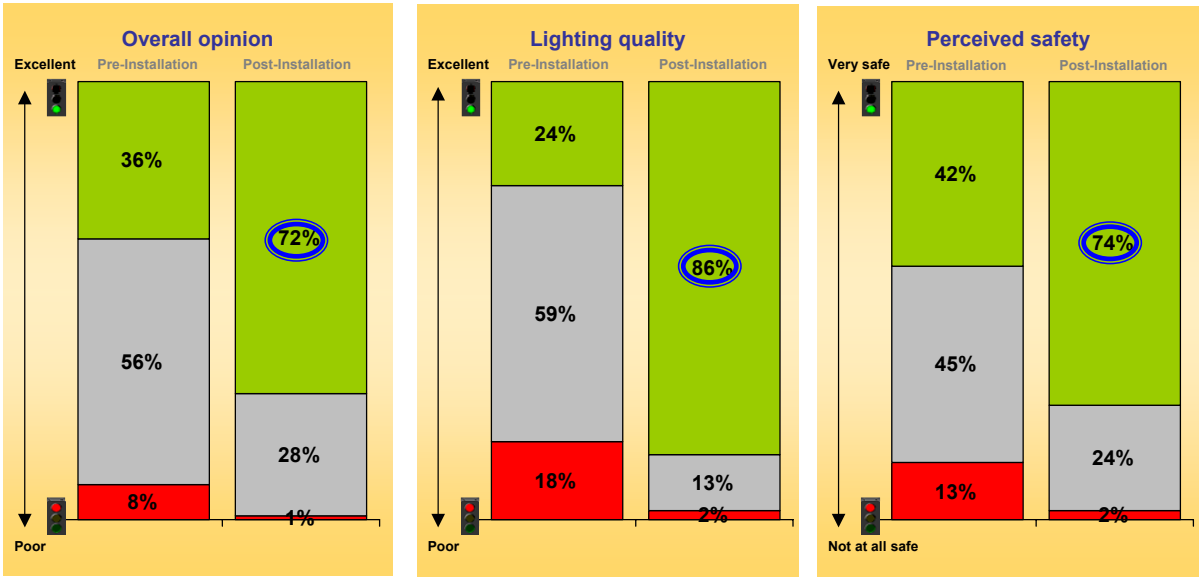
- Encourage the City of Raleigh and other parking facilities to install LED lighting throughout their facilities
- Focus on perceived safety improvements
- Stress benefits over traditional lighting
- Suggest LED lighting installation as an easier and more cost-effective method of addressing some of the more common parking facility issues

Significant improvement in the perception of lighting quality post-installation

- Positive reactions to the facility's lighting were over 3x higher post-installation
- Overall opinion of the parking facility and perceived safety also improved dramatically
- Both males and females felt significantly safer post-installation

Pre-Installation n=200
Post-Installation n=200

Positive (Top 3 Box)
Neutral (Middle 4 Box)
Negative (Bottom 3 Box)

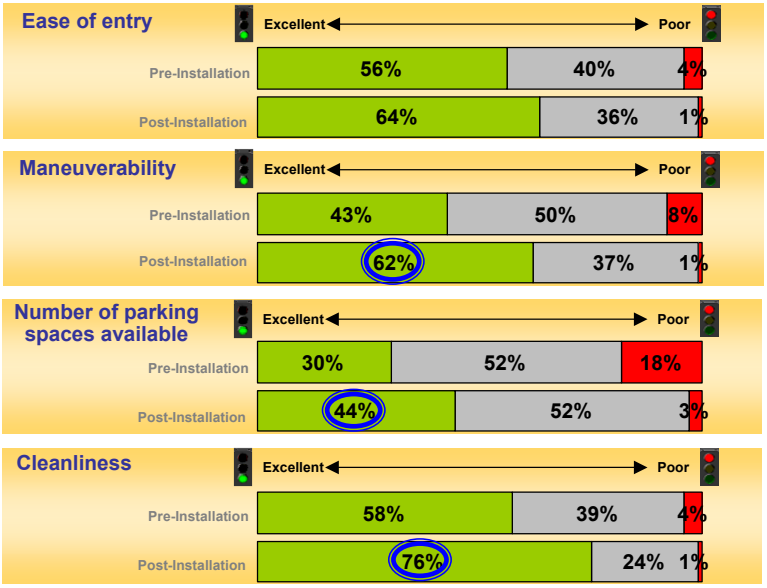


Q5.On a scale from 1 to 10, how would you rate the quality of the lighting in the parking facility?
Q6.On a scale from 1 to 10, how safe do you feel in the parking facility?
Q7.On a scale from 1 to 10, what is your overall opinion of the parking facility?

Indicates significant differences at the 95% confidence level

Respondents react more positively to garage experience after LED installation

- Positive responses to maneuverability within the facility, the number of available parking spaces, and cleanliness were also significantly higher post-installation



Pre-Installation n=200
Post-Installation n=200

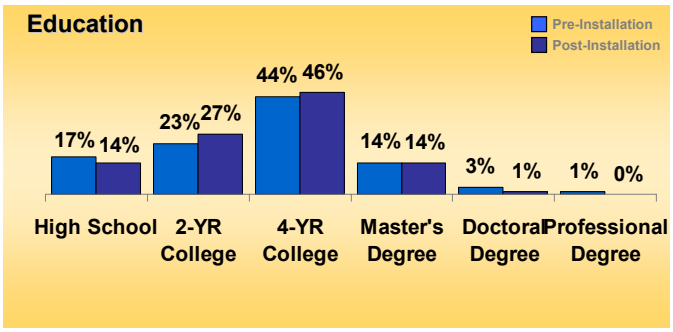
Positive (Top 3 Box)
Neutral (Middle 4 Box)
Negative (Bottom 3 Box)

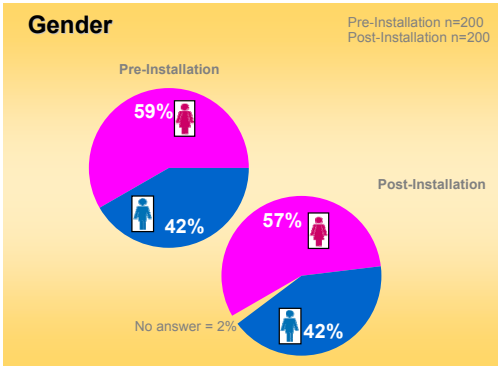
Indicates significant differences at the 95% confidence level

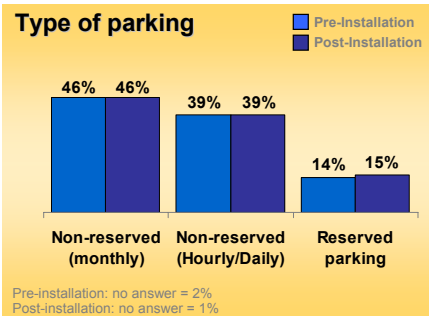
Q1. On a scale from 1 to 10, how would you rate the ease of entry to the parking facility?
Q2. On a scale from 1 to 10, how would you rate the maneuverability within the parking facility?
Q3. On a scale from 1 to 10, how would you rate the number of available parking spaces for hourly/daily (non-contract) parking?
Q4. On a scale from 1 to 10, how would you rate the cleanliness of the parking facility?

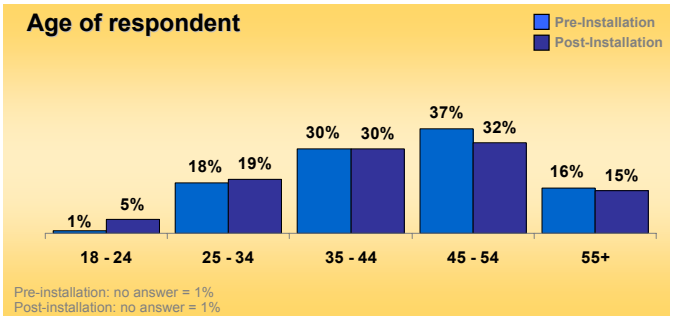
CREE Municipal Parking Survey Results

Respondent Profile









Q8. Are you currently employed by the City?
Q9. What type of parking did you use today?
Q10. What is your gender?
Q11. What is your age?

CREE Municipal Parking Survey Results

Economic Analysis

As identified in the above descriptions, the installation of LED lighting fixtures on level 3 of the Raleigh municipal parking garage has yielded several benefits – reduced energy consumption, greatly reduced maintenance activity and costs, improved light quality and increased customer satisfaction and feelings of safety. Given these positive results, the most common inquiries from those interested in this project relate to the economics of the installation, including initial cost, payback calculations, etc.

As noted earlier, LED lamp technology, as well as LED fixture technology and product offerings are rapidly evolving and improving, and we encourage those interested in pursuing LED lighting solutions to perform an independent economic analysis of their particular application using the latest LED lighting products available from fixture manufacturers. The economic analysis is sensitive to assumptions about electricity rates, labor rates, maintenance costs and product cost. In addition, a retrofit is quite different from a new install.

Initial Cost

The installation of LED light fixtures in the municipal garage is a pilot application designed to evaluate the costs and benefits of LED lighting. When evaluating the first cost, the City makes the assumption that they would be in a position of needing to buy new fixtures of some type. Therefore, the amount to consider for this economic analysis is the cost delta between the LED fixtures and fixtures using traditional light sources.

The quote for the initial 141 LED fixtures from LSG specified a list price to the City of $450 per fixture, or $63,450. Traditional fixtures, using an HID light source would have a list price of approximately $150 per fixture, or $21,150. The cost delta, therefore, is $42,300

Energy Savings

As described earlier, the installed LED fixtures on level 3 of the garage are delivering electricity savings of 46,720 kWh per year. At an average metered rate of $0.06 per kWh, this yields $2,803 of savings per year at current rates. The City's rates for electricity have risen steadily since 2000, and the City expects rates to continue rising by approximately 3% per year.

Also notable, these savings reflect the use of photocell sensor-based control of a portion of the lights, which reduces the electricity used by the garage lighting and hence the savings from the LED lights. Garage applications without this type of control, or underground garage applications, will experience greater savings due to 24-hour-a-day operation. Also, LEDs allow newer control technology, such as motion-detector switches, to become more viable in further reducing energy consumption because of the LED's instant-on/instant-off characteristics, which are not typical of older bulb technology.

Maintenance Savings

The annual maintenance budget for the 141 light fixtures on level 3 of the municipal garage is $3,500. Based on earlier budget assumptions, maintenance savings are $3,325 per year. Since LEDs do not typically suffer catastrophic light source failures, the inconvenience and potential safety hazards associated with "burned-out" bulbs are also avoided.

Payback

Using the figures from above, an initial investment of $42,300 yielding electricity savings of $2,803 per year and maintenance savings of $3,325 per year, each increasing 3% per year, would yield a payback during year seven. At the list price, and with a fixture product based on older LED technology, the payback period for the fixtures is approximately equal to the expected service life

for the fixtures that operate 24 hours a day and would allow the fixtures controlled by the photocell system to return energy savings for an additional five years of service. Of course, this analysis only considers the direct economic costs and does not account for the qualitative and environmental benefits of using LED lighting.

Outlook

LED performance is improving rapidly each year, and LEDs are already commercially available that are 75% more efficient than those used in the municipal garage fixtures. In addition, manufacturers are only now beginning to explore volume production of commercial LED light fixtures. As the technology continues to improve, and the fixture volumes increase, we can expect to see lower prices for LED fixtures. These developments may yield a markedly improved economic business case for LED lighting deployment.

Based on the results of the Raleigh analysis, any new construction project or retrofit utilizing low bay lighting should consider LED fixtures competitively with standard technology (particularly in regions of the country where the cost of electricity is substantially higher than Raleigh's). Communities should also consider financing mechanisms that allow the full life-cycle cost to be considered in the up-front procurement decision process. It does not appear at this time that the cost savings utilizing LED fixtures justify retrofitting existing facilities where the current light source has not reached the end of its usable life, unless such a retrofit is to be done based on the quality of light, not the economics of operating the facility. As the pricing structure of these fixtures and the efficiency of the LEDs within them changes, retrofit may become an increasingly attractive alternative, particularly in underground parking or other applications where 24/7/365 lighting is essential.

Conclusion

The Raleigh municipal garage pilot has been a successful test of LED lighting and has led to the City's decision to incorporate LED fixtures into a new 900+ space underground parking structure currently under construction. The expected electricity savings have been validated, as well as the significant improvement in the light quality over the incumbent HPS technology. As shown by the customer survey, the LED lighting also delivered a much improved user experience.

There is a rapidly-changing environment for LED lighting technology and products, as well as wide variations in electricity rates and maintenance costs between regions of the country and of the world. Because of this, individual project-by-project evaluations of potential LED lighting deployment in parking-structure applications should be undertaken.

That being said, it is clear from this pilot study that LED lighting provides very large opportunities today to save very significant amounts of electricity and maintenance costs. Beyond the economic considerations, deployment of LED lighting also reduces the impact on the environment of the City's parking operations, both by reducing the pollution from generating electricity and by reducing the waste from used light bulbs, improves the feeling of personal safety experienced by users of the garage and delivers higher quality light than the incumbent technology. In addition, unlike some traditional light bulbs, LEDs do not contain harmful lead or mercury, which further reduces the potential environmental impacts.