LED TAXIWAY LIGHTING ASSESSMENT

ET10SCE1260 Report

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Disclaimer

Abbreviations and Acronyms

ETEL	Elevated Taxiway Edge Light
fc	Footcandle
kWh	Kilowatt-hour
LED	Light Emitting Diode
MIPAA	March Inland Port Airport Authority
REIL	Runway End Identifier Lights
RGL	Runway Guard Lights
W	Watt

FIGURES

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EXECUTIVE SUMMARY

Southern California Edison's (SCE) Emerging Technology Program assesses products that have the potential to reduce electric energy use. One class of emerging technology is airport taxiway lights that use light emitting diodes (LEDs), a new application of evolving LED technology whose potential energy savings have not been quantified to date. The purpose of this project is to evaluate the potential energy savings attributable to LED taxiway lighting. The application is also evaluated to ensure no relative degradation in light output performance between old and new technology occurs.

The main objectives of this project are to:

- Measure the electric load profile of the existing incandescent baseline taxiway lights.
- Measure the aggregate electric load for both the old incandescent (baseline) and the LED (new measure) taxiway lighting at the three operating levels (Control tower operators modulate the taxiway light levels based on site visibility-fog/rain/daylight/dark/etc.-see details in Background section below).
- Calculate energy savings for replacement of incandescent with LED taxiway lights.
- Record by way of light meter illuminance readings the light output of an existing incandescent LED taxiway luminaire versus the new LED replacement luminaire.
- Document via use of reference photographic imagery visual comparisons of the existing incandescent system versus the new LED replacement luminaires.

In 2006, SCE initiated a power measurement study of a sample of taxiway lights for March Inland Port Airport Authority (MIPAA). An area of taxiway leading to the DHL air cargo terminal was selected to perform a pilot study. The replacement of 76 incandescent lights with LED lights is intended to save MIPAA energy and maintenance costs without sacrificing performance. Taxiway lights are generally operated when it is dark or when daylight visibility is reduced.

The energy use load profile of the existing taxiway lighting was monitored for eight months from September 2006 through May 2007 to capture the variation in light level operation. Data was collected from mid Sept through the end of May. June and July were projected using May data, since daylight hours and visibility should be similar for these periods. August and early Sept were projected based on late Sept and early Oct data. The annual percent time at each of the lighting levels was based on a full year of data where 3.5 months were projections that leveraged available data.

The existing lights are 45W and the new LED lights are rated at 11.2 VA. The maintenance costs should be significantly reduced since the rated life will go from 1,000 hours to 56,000 hours. Actual life will be longer since they are only operated at full intensity for a small percentage of time. Lighting level measurements of both luminaire types were made after dark. In late December 2010, the replacements were completed and power measurements of the three operating light level settings were conducted.

The monitored data was leveraged to project annual percent time that the taxiway lights were only operated at full intensity 1.4% of the time; mid-level 2.4% of the time, low level 32.7% of the time and off the remainder.

Photometric (footcandle) measurements were taken at three feet away since the light illuminance was so low. No lab testing was possible because of the constant current power supply system used for airport lighting.

The annual energy use of the existing luminaires was 10,431 kWh per year. The energy use of the LEDs is will be 4,959 kWh per year projecting the same load profile. This is a savings of 5,472 kWh per year or 72 kWh per year per light. The energy use is reduced by 52.5%. No demand savings is expected since the lights are typically off during the noon to 6:00 p.m. summer peak period.

Data collected via field evaluation and performance measurements of the existing incandescent taxiway luminaire versus the proposed LED taxiway luminaire at MIPAA were as follows:

- Illuminance readings, light output at three levels for existing incandescent LED taxiway luminaire and a new LED replacement luminaire. The LED luminaire produced between 25% to 35% higher illumination on the reference grid than did the existing incandescent base lighting.
- Reference photographic imagery 'visual comparisons' of the existing incandescent versus the proposed LED replacement luminaire both close-in (at 6-feet from sources) and far-out (25-30 feet from sources) also indicated that the LED out-performed the base incandescent visually.

The measure has a two-year payback - see Economics section including lifecycle costing. The measure can only receive incentives using the statewide-customized offering procedures.

The LED taxiway luminaire tested demonstrated its ability to provide superior way finding illumination at significantly lower power consumption than conventional incandescent taxiway luminaires. The substantially longer LED lamp life will also significantly reduce re-lamping maintenance.

LED luminaire technology is well suited for taxiway illumination, and should be encouraged based on the following:

- The LED light source, rich in blue wavelength light, provides greater visual impact than conventional incandescent lights with blue filters.
- Power consumption is drastically reduced with the LED taxiway lighting system over that of an incandescent system.
- Maintenance is minimized with the LED taxiway systems extended lamp life.

INTRODUCTION

Southern California Edison (SCE) has worked with the March Inland Port Airport Authority (MIPAA) to provide assistance evaluating the replacement of incandescent taxiway lighting with light-emitting diode (LED) lighting. A sample area of taxiway was selected to perform a pilot study. The blue taxiway edge lighting area retrofit is highlighted with blue lines in Figure 1. The DHL air cargo terminal is isolated from the main area of March Joint Air Reserve Base.

FIGURE 1. BLUE LINES SHOWS TAXIWAY LIGHTING RETROFIT AREA AT DHL AIR CARGO TERMINAL

The replacement of incandescent lighting with LED lights is intended to save MIPAA energy and maintenance costs without sacrificing performance. Successful implementation of this project will likely expand to the rest of the taxiway lighting at this facility. This report will provide a case study showing successful implementation of LEDs for taxiway lighting and provide reassurance to prospective implementers to proceed with installation of LEDs.

Airfield lighting is a category of lighting that can benefit from energy saving LEDs. There are many locations for application, including commercial airports, various types of military fields, and small and private airfields. Savings by going to LED are not limited to taxiway lights. Other developing LED applications are signs, Runway Guard Lights (RGL), windcones, runway centerline, medium intensity runway, touchdown zone, Runway End Identifier Lights (REIL), obstruction, and high-intensity runway edge lights.

BACKGROUND

Airfield lighting is designed to produce a consistent level of light for a setting. There are three light level settings in addition to off, full on (level 3), medium (level 2), and low (level 1). The operation of this 3-step system follows United States Air Force rules to assure adequate visibility and displays in Table 1.

TABLE 1. TAXIWAY LIGHT LEVEL OPERATION BY STEPS

STEP	VISIBILITY: DAY	VISIBILITY: NIGHT
3	< 1 mile	When Requested
2	When requested	< 1 mile
1	When requested	=> 1 mile

Except:

a. Where a facility directive specifies other settings or times to meet local conditions.

b. As requested by the pilot.

c. As tower operators deem necessary, if not contrary to pilot request.

The levels are manually set by the tower based on visibility conditions. The lights are off during the day if visibility is greater than 1 mile (unless precluded by any of the exceptions listed above). The lights are on at night (unless precluded by any of the exceptions listed above).

The ground - mounted lighting along taxiways and runways are powered by constant current regulating transformers. If a lamp burns out in a series loop circuit the transformer provides a constant source of current which makes the other lamps brighten to make up for the lost lamp.

Taxiway lights are blue in color to designate the type of area they define. Following are descriptions of the incandescent and LED lighting that were part of this study.

EXISTING TECHNOLOGY

The existing conventional technology uses incandescent lamps in a flush ground mounted fixture. The lamp is General Electric model 23310, which is 45 Watts and a PAR56 style. It is rated at 6.6 Amps, 700 lumens and 1,000-hour life. They are a white light source so are mounted with a blue lens (see Figure 2) to filter the light and provide distinctive blue light.

FIGURE 2. CONVENTIONAL TAXIWAY LIGHT EXTRACTED FROM GROUND MOUNTING.

EMERGING TECHNOLOGY/PRODUCT

LEDs have made rapid strides in recent years. The efficacy of LEDs has improved so they can replace many types of light sources. LEDs have the advantage over some technologies because they are also dimmable.

The product selected for use in this study is a Siemens Signature Series™ L-861T LED Elevated Taxiway Edge Light (ETEL), see Figure 3. The ETEL models use a single LED and are rated at 11.2 VA load using a 30/45 W isolation transformer. They are ETL certified. The LED is rated for 56,000 hours in high mode and is expected to last 150,000 hours in typical taxiway operation. This product meets Federal Aviation Administration, International Civil Aviation Organization and Federal Communications Commission standards. It has an operating temperature range of -67 °F to 131°F.

LEDs in this application have many advantages. They are fully dimmable. The lower energy use will reduce energy costs. The lower wattage will allow airport staff to add more lights without replacing the constant current transformer. LEDs can be used for taxiways, centerline, runways and other airfield lighting. Long life will significantly reduce maintenance costs historically high due to burnouts.

The elevated edge lights are more vulnerable to breakage from airfield vehicles compared to the flush ground-mounted lights in Figure2.

FIGURE 3. ELEVATED LED TAXIWAY LIGHT.

ASSESSMENT OBJECTIVES

The two main objectives for this study are to show energy savings and confirm quality of light is not compromised.

Objectives for on-site field evaluation and performance measurements of a new LED taxiway luminaire at MIPAA were as follows:

- Measure the electric load profile of the existing lamps taxiway lighting.
- Measure the aggregate electric load for both the old incandescent (baseline) and the LED (new measure) taxiway lighting at three operating levels.
- Calculate energy savings for replacement of incandescent with LED taxiway lights.
- Record by way of light meter illuminance readings the light output of an existing incandescent LED taxiway luminaire versus the new LED replacement luminaire.
- Document via use of reference photographic imagery visual comparisons of the existing incandescent system versus the new LED replacement luminaires
- Document both light meter measurements as well as visual images with reference to the incandescent and LED luminaires used in the evaluation.
- Provide data analysis and evaluation of data collected as well as provide preliminary recommendations based on findings gained via analysis and evaluation.

TECHNOLOGY/PRODUCT EVALUATION

An active taxiway operated by MIPAA in Moreno Valley, CA was selected by Southern California Edison as the test site location. The technology evaluation of taxiway lights was conducted in field conditions at MIPAA. Replicating the constant current source transformer power source in the laboratory was not practical.

The connection of the taxiway with a military and commercial airfield field meant restricted access to the lighting circuits and taxiway lights. Security clearance and advance notice were required before each site visit.

An early attempt to measure the light levels using conventional indoor meters was not successful. The very low light level output by the luminaire-required instrumentation specially designed for low illuminance.

TECHNICAL APPROACH/TEST METHODOLOGY

The technical approach and test methodology is divided into two distinct categories. One is the energy used by the old and new systems while the other focuses on the measured and qualitative light outputs of the two systems.

FIELD TESTING OF TECHNOLOGY - ENERGY

The following describe the field testing of the technology.

- Energy use of the taxiway lighting circuits was measured and recorded using a multi-channel meter recorder.
- Two circuits were monitored which covered all 76 power points for the old incandescent and the new LED's. Circuit TL7 feed by breaker #9 in panel L-2 is for the alert taxiway north and circuit TL8 feed by breaker #5 in panel L-2 is for the alert taxiway south.
- Each circuit has its own constant current regulating transformer for the series operation of taxiway lights.
- Initially data was recorded in 5-minute intervals providing the average demand during the interval. After several months, the interval was changed to 15-minutes to optimize logger memory and minimize trips to download data.
- The baseline incandescent fixture tested was two (2) years old. It was deemed new enough and therefore not relamped. IESNA data (Fundamentals Handbook-current 9th ed. Figure 6-20) indicates it can have lost about 7.5% of its original light output since installed.

FIELD TESTING OF TECHNOLOGY - ILLUMINANCE

The following describe the field testing of the technology.

- Seventy-four (74) of the seventy-six (76) flush ground mounted current incandescent taxiway lights are approximately forty (40) years old. Of the remainder two (2) lights (each had only two (2) years in service) one (1) was used as baseline for testing.
- The current proposal for airport improvements call for up-grading the taxiway lighting with a newer design which offers improved performance as well as lower maintenance.
- An LED taxiway luminaire has been proposed as the replacement luminaire for taxiway illumination. An operational sample of the proposed LED taxiway luminaire was installed within the taxiway illumination pattern adjacent to the existing system.
- Baseline incandescent and LED sources are virtually linear as to power and light as they are dimmed.

- Multi-level control of MIPAA taxiway lighting is currently in place. Three levels of intensity, controlled from the tower, are available. The three levels are defined as follows:
    - LEVEL 3: Full (100%) light output from luminaire
    - LEVEL 2: Medium (30%) light output from luminaire
    - LEVEL 1: Low (10%) light output from luminaire
- Both "base lighting" existing incandescent and "proposed" LED taxiway luminaires were tested at all three control levels.

TEST PLAN - ENERGY

- The test plan was to monitor the existing taxiway light circuits surrounding the DHL terminal for several months. The typical operation of lighting levels maintained for the 76 lights would be captured.
- Interval data would be segregated into four categories: Off, Low (step 1), Medium (step 2), and High (step 3). The percent time the taxiway lighting was operated in each category would be calculated.
- Data collection initially started in September 2006 with anticipation the retrofits would occur in early 2007. After approximately eight months, the monitoring equipment was removed at the end of May 2007. The project was suspended for three years. Data collection was restarted in October 2010.
- Post retrofit data collection was anticipated to collect at least a month of data. Due to additional delays, some caused by weather, the post data collection merely amounted to measuring the power at the three different level settings. The monitoring equipment was in place for less than 24 hours after LED retrofits were completed. The post period included two test periods, one where the lights were operated for 35 minutes at each level and the other where the lights were operated for one hour at each level.

TEST PLAN - ILLUMINANCE

- The proposed LED luminaire was installed at an existing incandescent luminaire location, which is currently part of the active taxiway lighting system; see Figure 4 and Figure 5.
- An existing incandescent luminaire was selected for baseline testing of the existing system. Since the existing system is over 40 years old care was taken to find an example of "best condition" luminaires with minimum degrading and wear and tear. Note that the majority of luminaires in the system are near end of useful life showing excessive wear and degrading due to excessive age, see Figure 6 and Figure 7.

FIGURE 4. INDEPENDENT CONTRACTOR INSTALLS TEST LED TAXIWAY LUMINAIRE ON EXISTING POWER POINT, BY REPLACING EXISTING INCANDESCENT LUMINAIRE

FIGURE 5. LED TAXIWAY LUMINAIRE ON EXISTING POWER POINT READY FOR TESTING

FIGURE 6. MOST OF THE EXISTING INCANDESCENT LUMINAIRES ARE NEAR END OF USEFUL LIFE (40 YEAR AGE). AS A RESULT PERFORMANCE IS WELL BELOW TYPICAL PERFORMANCE FOR THIS STYLE LUMINAIRE.

FIGURE 7. A LUMINAIRE WITH REASONABLY GOOD LENS AND REFLECTOR WAS SELECTED FOR BASELINE TESTING. THE LUMINAIRE WAS ALSO CLEANED BEFORE MEASUREMENTS WERE RECORDED

INSTRUMENTATION PLAN - ENERGY

To monitor power an Enernet K-20 multi-channel meter recorder was used. This recorder can monitor electric energy, analog signals and digital pulses. It was used to monitor true rms kW power of two transformers feeding the taxiway lights. The logger accuracy for a power measurement is ±0.5% from 1 to 100% of full scale. Current transformer accuracy is ± 1% from 10% to 100% of full scale, ± 3% at 5% of full scale and ±5% at 2% of full scale. Split-core current transducers with 25 Amp primary ratings were used. Two of the eight channels were used. The meter samples the full 60 Hz waveform once every 5 to 9 seconds. The data samples are averaged and recorded in 5-minute intervals. The meter recorder is the box mounted below breaker panel L-2 shown in Figure 8.

FIGURE 8. POWER RECORDER MOUNTED BELOW ELECTRICAL PANEL

INSTRUMENTATION PLAN - ILLUMINANCE

- Illuminance readings were obtained using a Minolta T10 illuminance meter Performance specifications for the Minolta T10 are described with the image of the meter, see Figure 9.
- Illuminance readings were taken three feet (3-FT) from the incandescent reference taxiway light and proposed LED taxiway light sources. A two foot (2-FT) by three foot (3-FT) white board placed three feet from the light source of each luminaire was used as the target reference plane for measurements. Measurements taken were vertical footcandles (fc) see Figure 10.

Illuminance Meter T-10 <standard receptor head>

Used for measurement of a wide range of illuminance

(0.01 to 299,900 lx
0.001 to 29,990 fcd)

Minolta T-10 SPECIFICATIONS

Type:	Digital illuminance meter with detachable head and cable
Receptor:	Silicon photocell
Range:	0.1 – 200,900 Lux 0.001 – 29,990 footcandles
Accuracy:	+- 2% +-1 digital value displayed
Purchase & Calibration:	August 14, 2010 *(1876-242)*

FIGURE 9. MINOLTA T10 ILLUMINANCE METER USED FOR MEASUREMENTS

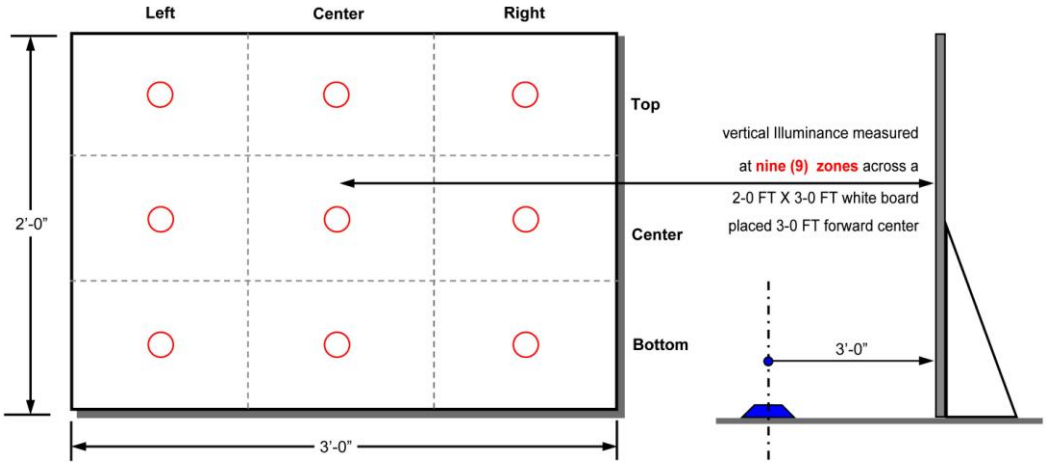


FIGURE 10. 2-FOOT X 3-FOOT WHITEBOARD TARGET FOR ILLUMINANCE READINGS

- Single lens reflex camera and Canon 17mm to 85mm high resolution image stabilized lens, see Figure 11 and Figure 12.
- Reference images (nighttime operational) were taken with camera set at ISO 200 and manual mode with aperture at f 5.6 fixed. Shutter speed adjusted as requires producing equivalent visual illumination in photographs between incandescent base and LED proposed new lighting
- Reference images of luminaires were rerecorded close-in (6-feet from luminaire) and far-` out (25-30 feet from luminaires). Camera was placed at eye level for both close-in and far-out images. All images were recorded at luminaire Level 3 output and the camera at eye level; see Figure 13 and Figure 14. White board image recordings were taken in same plane as each source, 3 ft. away endo to the board at its center; see Figure 10.

FIGURE 11. CANON 450D SLR

FIGURE 12. CANON EFS 17-85MM LENS

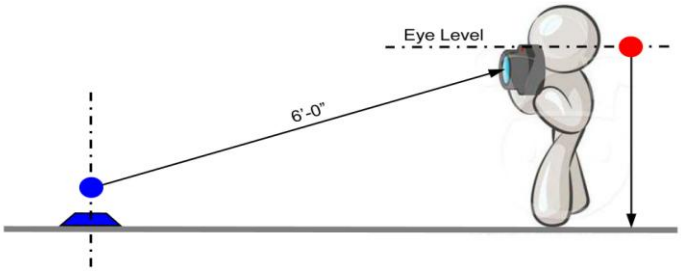


FIGURE 13. CLOSE IN DOCUMENTATION

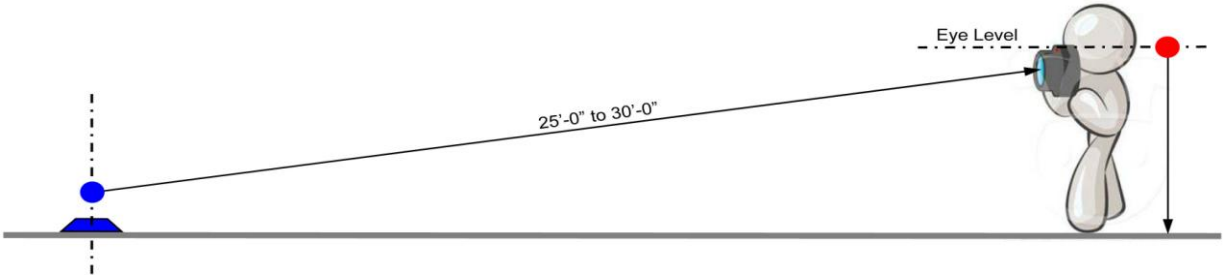


FIGURE 14. FAR OUT DOCUMENTATION

RESULTS

The power was monitored for two taxiway circuits for eight months from September 2006 to May 2007. For presentation and analysis the data for the two circuits is combined and represent the 76 taxiway lights that are part of this study. Figure 15 shows that when the lights were on that they were in low mode (approx. 3 kW) most of the time. The few spikes showing operation in the medium and high level only occurs occasional when conditions require more illumination. Several taxiway lights were removed for approximately three months early in 2007.

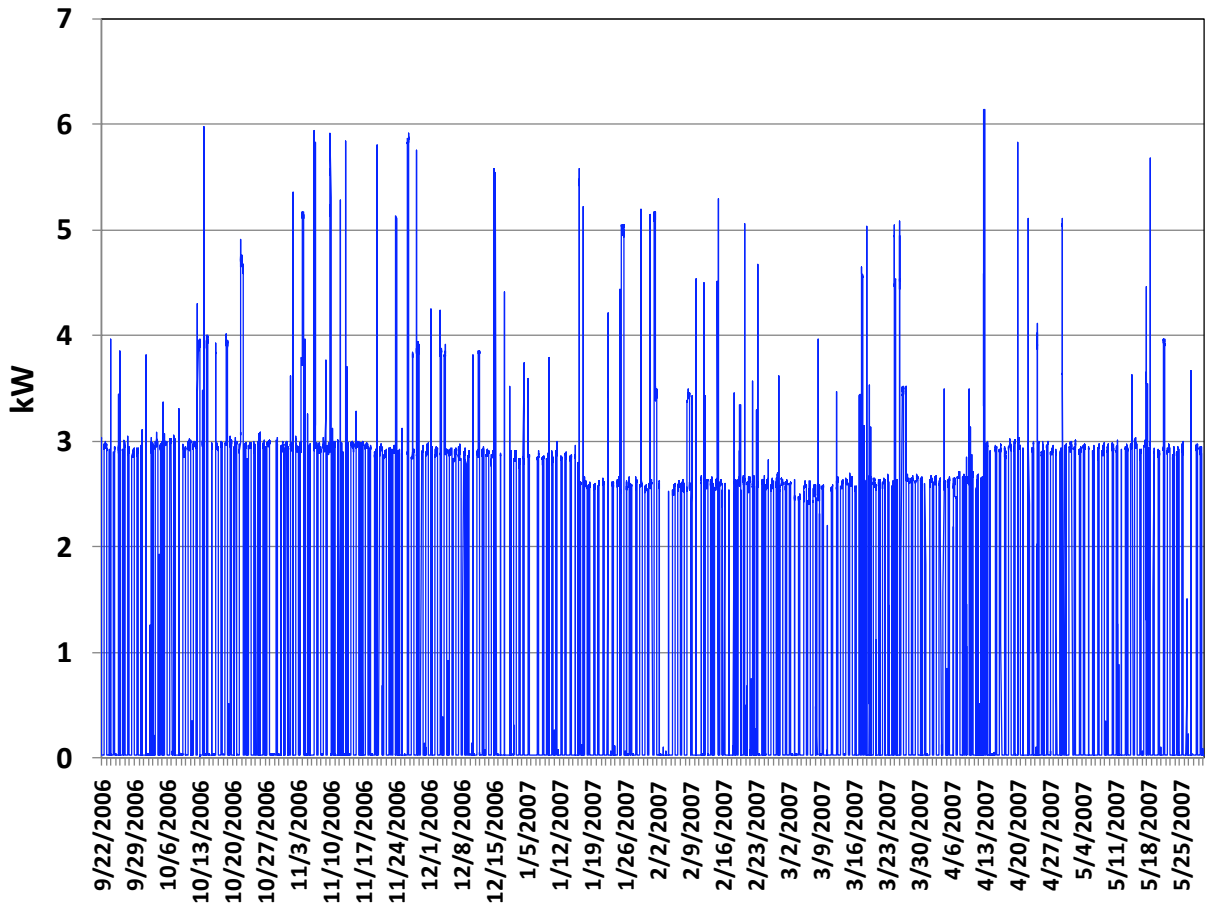


FIGURE 15. EIGHT MONTH PROFILE OF TAXIWAY LIGHTING ELECTRIC LOAD

Taxiway lights are generally operated when it is dark or visibility is reduced. The average hourly profiles for all monitored baseline data (September 2006 through May 2007) and just for May 2007 are presented in Figure 16. May is expected to be similar to other summer months. The May average shows the lights are completely off during the afternoon so there is no peak demand impact.

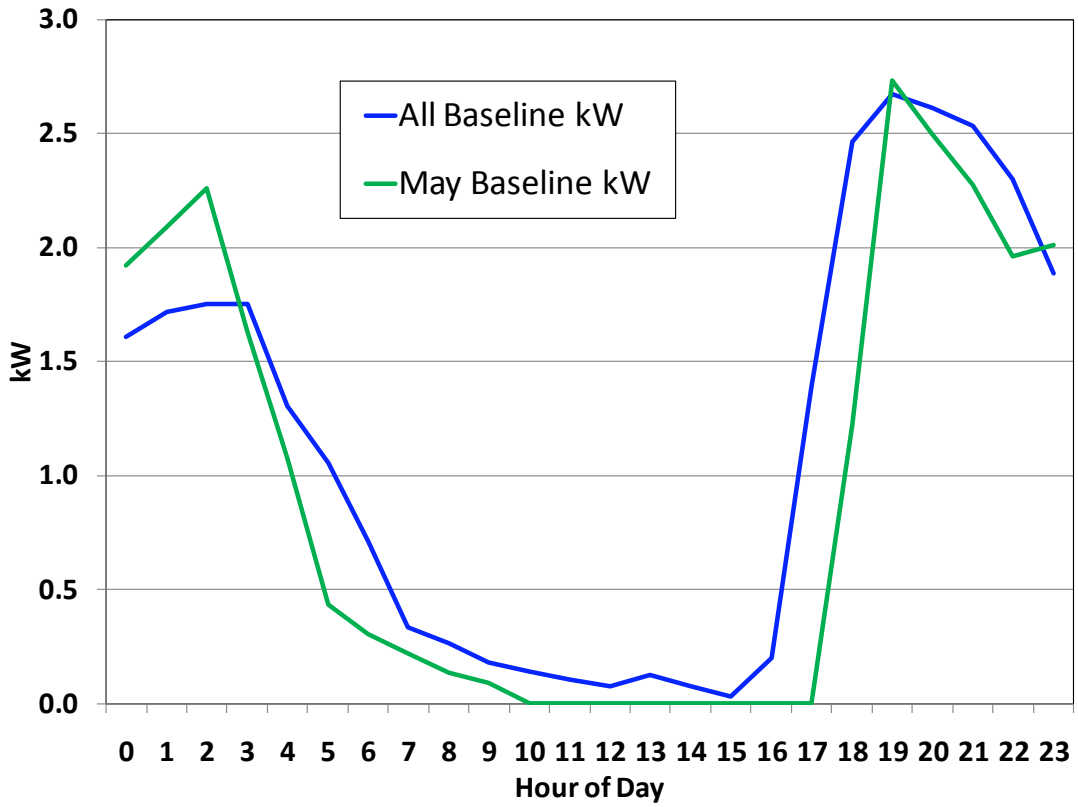


FIGURE 16. AVERAGE 24 HOUR PROFILE FOR BASELINE TAXIWAY LIGHTS

Light quality data collected via field evaluation and performance measurements of the existing incandescent taxiway luminaire versus the proposed LED taxiway luminaire at MIPAA were as follows:

- Illuminance readings, light output at three levels for existing incandescent LED taxiway luminaire and a proposed LED replacement luminaire. The LED luminaire produced between 25% to 35% higher illumination on the reference grid than did the existing incandescent base lighting.
- Reference photographic imagery' visual comparisons' of the existing incandescent versus the proposed LED replacement luminaire both close-in (at 6-feet from sources) and far-out (25-30 feet from sources also indicated that the LED out preformed the base incandescent visually.
- Additional photographic imagery' visual comparisons' of the existing incandescent versus the proposed LED replacement luminaire were collected and all imagery supports the superior performance of the LED taxiway luminaire over the base incandescent lighting.

DATA ANALYSIS

The data interval power data was categorized into four level settings. Above 4.2 kW was set as high, between 3.2 and 4.2 kW as medium, between 0.5 and 3.2 kW as low and below 0.5 kW as off. The projected annual percent time in each level category is shown in Table 2 and Figure 17. The lights were typically on week nights and off most of the weekend nights. The post retrofit energy use was calculated based on percent time at each level and average power readings at each level. The

average power readings for baseline and post lighting levels are also shown in Table 2. The annual energy use of the exiting luminaires was 10,431 kWh per year. The energy use of the LEDs is calculated to be 4,959 kWh per year. This is a savings of 5,472 kWh per year or 72 kWh per year per light. The energy use is reduced by 52.5%. No demand savings is expected since the lights are typically off during the noon to 6:00 p.m. summer peak period. The projected annual energy use for baseline and LED luminaires is presented in Figure 18.

TABLE 2. PERCENT TIME TAXIWAY LIGHTS OPERATE AT LIGHT LEVELS AND POWER READINGS

LIGHT LEVEL	ANNUAL PERCENT TIME IN LEVEL MODE	BASELINE KW	POST KW
High (Level 3)	1.0%	6.45	2.647
Medium (Level 2)	2.4%	4.24	1.950
Low (Level 1)	32.4%	3.16	1.521
Off	64.2%	0	0

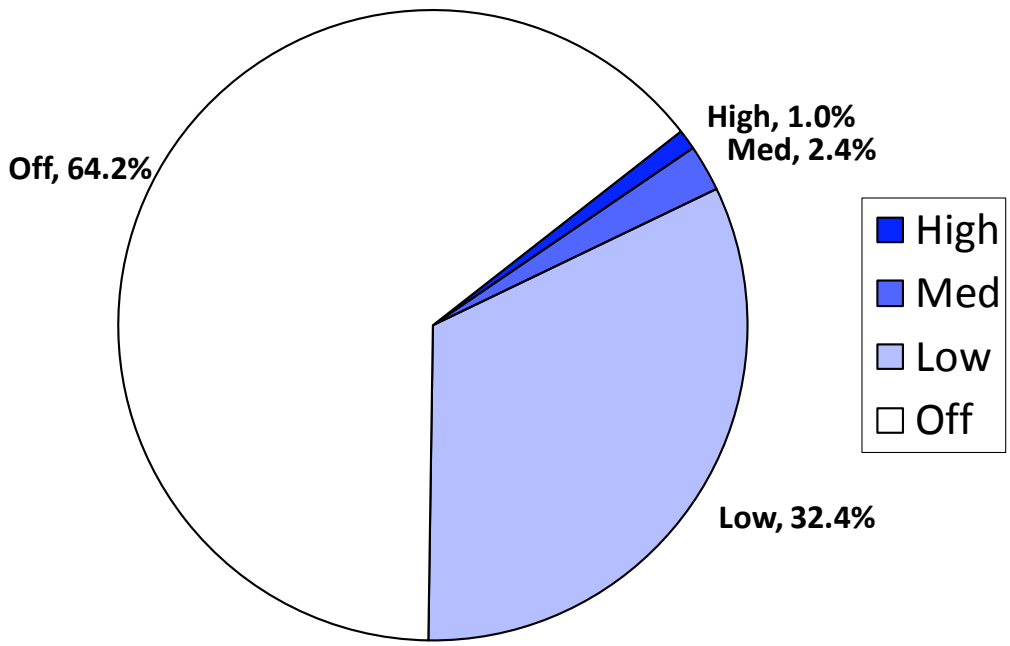


FIGURE 17. ANNUAL PERCENT TIME TAXIWAY LIGHTS ARE AT VARIOUS LIGHT LEVELS

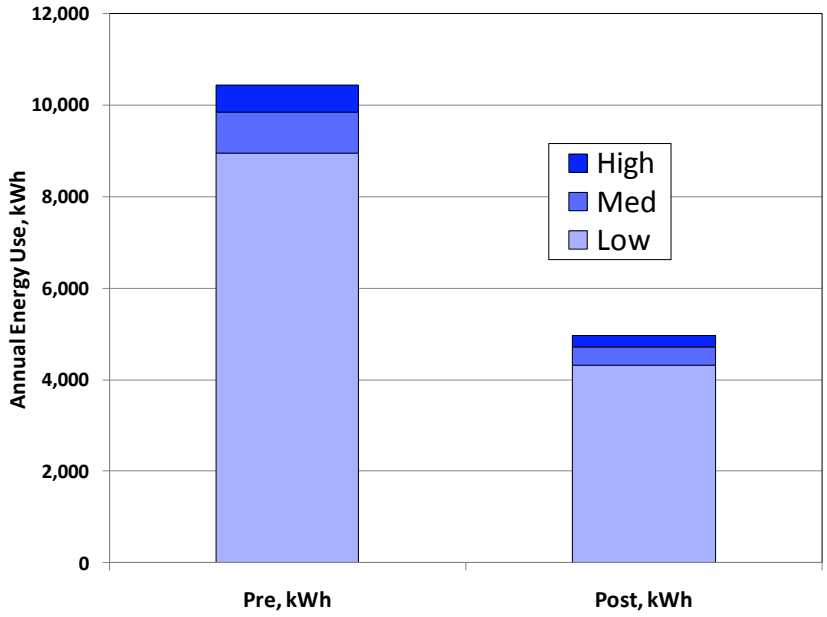


FIGURE 18. ANNUAL ENERGY USE FOR BASELINE AND LED TAXIWAY LIGHTS

The data was analyzed further to present average profiles for a 24-hour period. The percent time the taxiway lights were in each mode of operation were tabulated by hour of the day and are shown in the chart in Figure 19. The lights are off most of the time during the day, but also most weekend nights. The highest rate of full on operation occurs between 8 and 9. Typical flight activity includes eight arrivals week nights between hours 21 and 2, and eight departures weeknights between hours of 2 and 4.

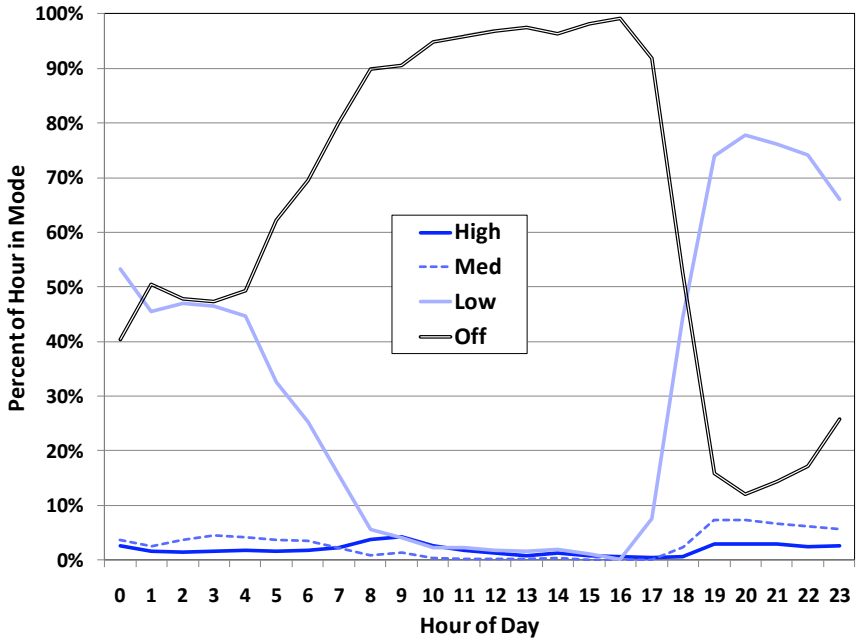


FIGURE 19. HOURLY PROFILE SHOWING PERCENT TIME ON IN EACH MODE BY HOUR

Next, weather data was collected from the airport weather station (KRIV) located near the runway coincident with the monitoring period. The weather data includes visibility in miles and qualitative sky conditions. This data was merged with the

monitored data to investigate the correlation between visibility and mode of taxiway lighting operation. All hours of the day and night are included in the analysis. Figure 20 shows the percent time across all visibility ranges the taxiway lights were in each mode of operation. The taxiway lights operated in high mode under all ranges of visibility and did not strictly follow the operating modes described in the background section, unless the condition "when requested" to used significantly.

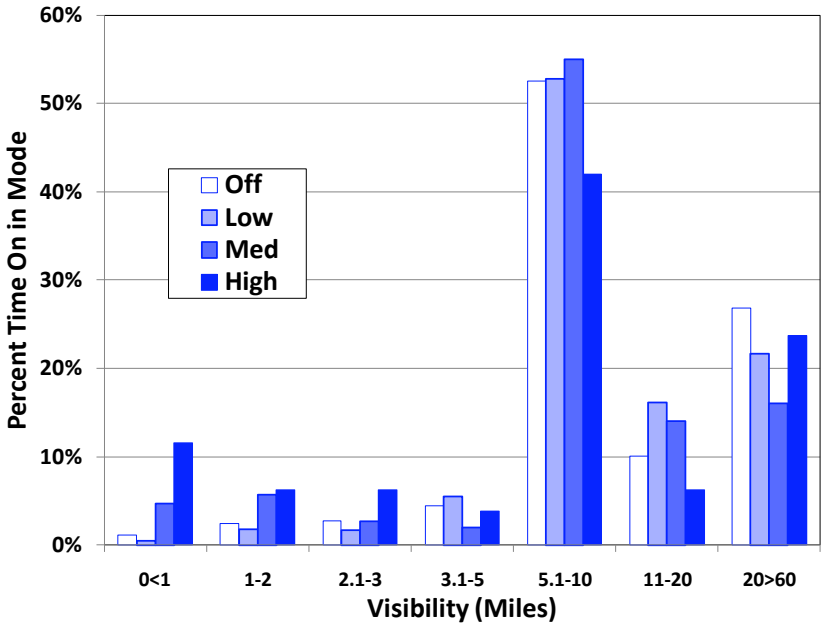


FIGURE 20. PERCENT TIME ON IN EACH MODE ACROSS VISIBILITY RANGES

The weather data was cross correlated between sky conditions and visibility. Although there were 22 different qualitative descriptions in the weather file we have grouped them into four main categories: Clear, Rain, Clouds, and Fog/Mist. Figure 21 shows the percent time the conditions were in each category of sky condition and range of visibility.

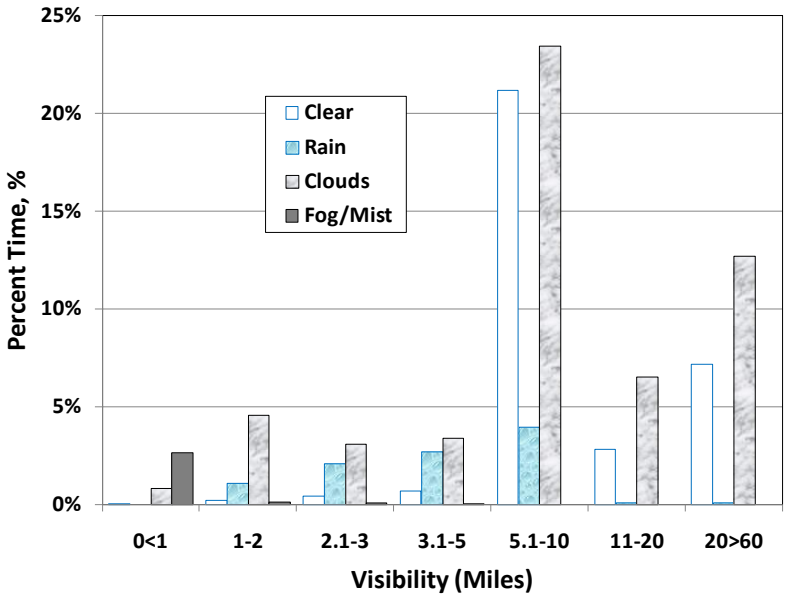


FIGURE 21. PERCENT TIME WEATHER CONDITIONS AND VISIBILITY RANGES EXIST FOR MONITORING PERIOD

Illuminance measurements for incandescent and LED luminaires are compared in Figure 22. The LED produces 25% more light in level 3 (high mode) and 35% more light in level 1 & 2 than the incandescent luminaire. The power consumptions listed in Figure 22 are rated values not measured values. Also in Figure 22, the max/min uniformity ratio of the LED improves from 19% to 32% over the incandescent. The detailed point by point illuminance measurements are presented in Figure 23.

ILLUMINANCE MEASUREMENTS AIRPORT TAXI LIGHT - DATA RECAP

45W PAR56 TAXI LIGHT		10W LED TAXI LIGHT		LED EFFICIENCY
LEVEL 3 - Full Light Output		**LEVEL 3 - Full Light Output**		
AVE FOOT-CANDLES:	0.112 FC	AVE FOOT-CANDLES:	0.139 FC	25% (light level)
UNIFORMITY RATIO:	7.2 : 1 (Max/Min)	UNIFORMITY RATIO:	5.2 : 1 (Max/Min)	28% (improvement)
MEASURED LIGHT OUTPUT:	100%	MEASURED LIGHT OUTPUT:	100%	NA
POWER CONSUMPTION:	45W	POWER CONSUMPTION:	10W	35W (saved)
LEVEL 2 - 30% Step Output		**LEVEL 2 - 30% Step Output**		
AVE FOOT-CANDLES:	0.042 FC	AVE FOOT-CANDLES:	0.058 FC	35% (light level)
UNIFORMITY RATIO:	5.7 : 1 (Max/Min)	UNIFORMITY RATIO:	3.9 : 1 (Max/Min)	32% (improvement)
MEASURED LIGHT OUTPUT:	38%	MEASURED LIGHT OUTPUT:	42%	NA
POWER CONSUMPTION:	Not Measured	POWER CONSUMPTION:	Not Measured	NA
LEVEL 1 - 10% Step Output		**LEVEL 1 - 10% Step Output**		35% (light level)
AVE FOOT-CANDLES:	0.021 FC	AVE FOOT-CANDLES:	0.028 FC	
UNIFORMITY RATIO:	3.2 : 1 (Max/Min)	UNIFORMITY RATIO:	2.6 : 1 (Max/Min)	19% (improvement)
MEASURED LIGHT OUTPUT:	20%	MEASURED LIGHT OUTPUT:	20%	NA
POWER CONSUMPTION:	Not Measured	POWER CONSUMPTION:	Not Measured	NA

FIGURE 22. ILLUMINANCE MEASUREMENTS OF TAXIWAY LIGHTS

ILLUMINANCE MEASUREMENTS INCANDESCENT VERSUS LED AIRPORT TAXI LIGHT

Details - Point by Point Measurements

45W PAR56 TAXI LIGHT

LEVEL 3 - Full Light Output AVE: **0.112 FC** Min/Max: 7.2

	Left	Center	Right
Top	0.064	0.039	0.050
Center	0.130	0.054	0.111
Bottom	0.183	0.097	0.281

LEVEL 2 - 30% Step Output AVE: **0.042 FC** Min/Max: 5.7

	Left	Center	Right
Top	0.025	0.018	0.021
Center	0.055	0.026	0.042
Bottom	0.062	0.028	0.103

LEVEL 1 - 10% Step Output AVE: **0.021 FC** Min/Max: 3.2

	Left	Center	Right
Top	0.015	0.013	0.014
Center	0.026	0.014	0.021
Bottom	0.031	0.016	0.042

10W LED TAXI LIGHT

LEVEL 3 - Full Light Output **AVE: 0.139 FC** Min/Max: 5.2

	Left	Center	Right
Top	0.093	0.107	0.053
Center	0.205	0.277	0.189
Bottom	0.103	0.119	0.102

LEVEL 2 - 30% Step Output **AVE: 0.058 FC** Min/Max:3.9

	Left	Center	Right
Top	0.038	0.044	0.033
Center	0.094	0.115	0.077
Bottom	0.041	0.051	0.029

LEVEL 1 - 10% Step Output **AVE: 0.028 FC** Min/Max:2.6

	Left	Center	Right
Top	0.021	0.022	0.019
Center	0.042	0.050	0.037
Bottom	0.019	0.023	0.016

FIGURE 23. POINT BY POINT ILLUMINANCE MEASUREMENTS

PHOTOGRAPHIC IMAGES

REFERENCE IMAGES INCANDESCENT VERSUS LED

All reference images were taken with fixed settings of ISO 200 (sensitivity), daylight (white balance) and 5.6 F stop (aperture opening). Shutter speed was then adjusted accordingly to recorded properly exposed images. The following photos were taken with luminaires in Level 3 (full light output) mode.

- Reference images close-in, see Figure 24 and Figure 25
- Reference images far-out, see Figure 26 and Figure 27

FIGURE 24. INCANDESCENT TAXIWAY LUMINAIRE "CLOSE IN" SHUTTER SPED: 1/50 SECOND

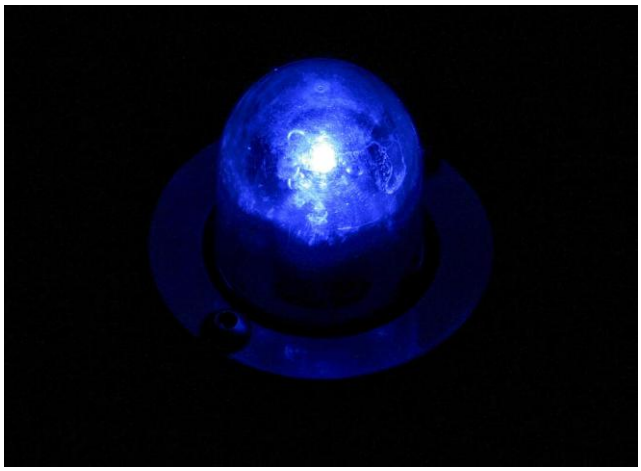


FIGURE 25. LED TAXIWAY LUMINAIRE "CLOSE-IN" SHUTTER SPEED: 1/125 SECOND

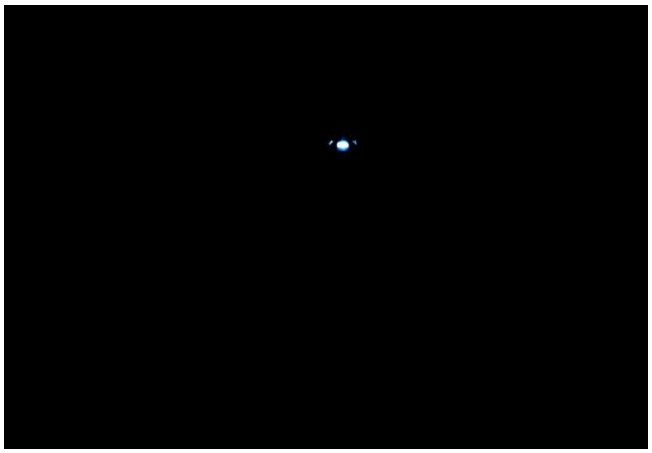


FIGURE 26. INCANDESCENT TAXIWAY LUMINAIRE "FAR OUT" (25-30 FT. FROM SOURCE) SHUTTER SPED: 1/15 SECOND

FIGURE 27. LED TAXIWAY LUMINAIRE "FAR-OUT" (25-30 FT. FROM SOURCE)SHUTTER SPEED: 1/30 SECOND

IMAGES OF WHITE BOARD AT 3-FEET FROM LIGHT SOURCE - INCANDESCENT VERSUS LED

Illuminance on white board recorded with luminaires at Level 3 "full light output" mode. Image of white board with illuminance from incandescent source luminaire is shown in Figure 28. Image of white board with illuminance from LED source luminaire is shown in Figure 29.

FIGURE 28. ILLUMINANCE ON 2 X 3 "WHITE BOARD" INCANDESCENT GROUND MOUNT TAXIWAY LUMINAIRE

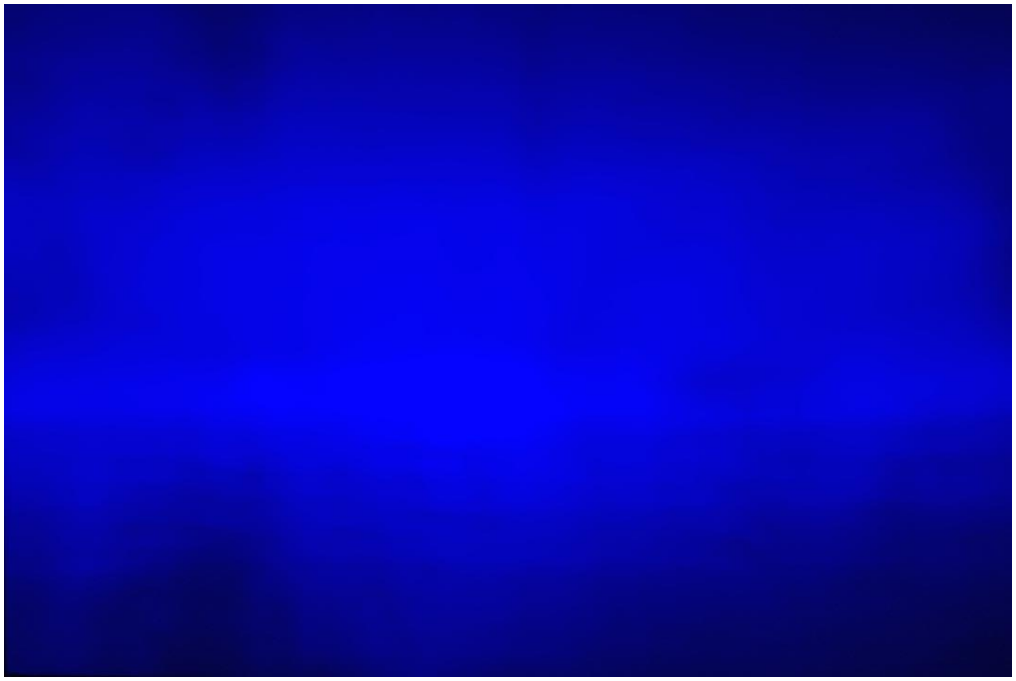


FIGURE 29. ILLUMINANCE ON 2 X 3 "WHITE BOARD" LED ELEVATED TAXIWAY LUMINAIRE

Additional Images depicting Test LED Luminaire with Adjacent Existing Incandescent Taxiway Luminaires

This section shows photos of luminaires taken at Level 3 "full light output" mode. A baseline incandescent flush ground mount taxiway luminaire to the left of the test elevated LED luminaire is shown in Figure 30. Figure 28 is a night view of a taxiway where one (1) LED test luminaire (to the center right) was installed. The other 10 taxiway lights visible in the shot are baseline incandescents. Also in the shot is a bright red/yellow with white light visible to the center left-it is a taxiway identifier sign. The photo in Figure 31 is taken from atop fuel storage tank adjacent to taxi strip.

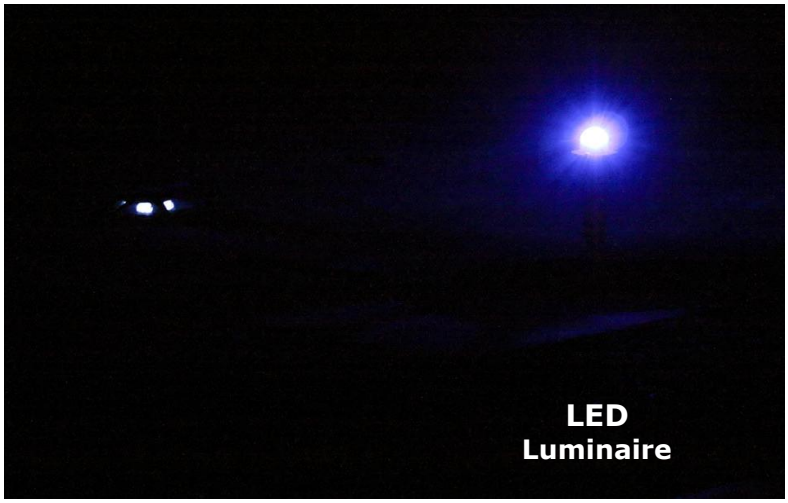


Figure 30. LED Taxiway Luminaire (Right) Exhibits Significantly Brighter Image Than Incandescent Luminaire (Left)

Figure 31. LED Taxiway Luminaire (Far Right) Viewed from Distance Along with Several Existing Incandescent Luminaires. LED Luminaire Exhibits Superior Visual Identity

The photo in Figure 32 was taken the night of December 28th after the retrofits were complete and shows the LED taxiway luminaires in operation.

FIGURE 32. LED TAXIWAY LUMINAIRE VIEWED ON NIGHT OF RETROFIT COMPLETION

ECONOMICS

To estimate the life cycle costs for the taxiway lights, the following technical and economic considerations are applied. The taxiway lights were at the end of their life and would be replaced by new fixtures, either direct replacement of like type incandescent or new LED above ground fixtures.

The installed cost for the 76 LED fixtures was $42,500. Half of that cost was installation or $279 per light. The installation costs for either fixture type are assumed to be $279 per fixture. The material cost for the incandescent fixtures is assumed to be $180 each.

All lights are operated 3,200 hours per year at the levels previously described in Table 1. The maintenance cost for the lights are $80 per year per light. Maintenance costs are applied to all 76 incandescent lights, but only 5% (4) of the LED lights. Energy cost is based on $0.15 per kWh.

A real discount rate of 3% (e.g., 5.0% investment interest rate minus 2.0% inflation) is applied to costs associated with maintenance costs and energy costs. The life of the fixtures is 25 years.

The life cycle costs are presented in Table 3. This table lists the net present value of the annual expenditures associated with the Incandescent and LED lights. The

break-even point is at the end of the second year, so the LED lights have a 2 year payback.

TABLE 3. ANNUAL AND ACCUMULATIVE ENERGY AND MAINTENANCE COSTS FOR INCANDESCENT AND LED LIGHTS

	Annual Energy Costs		Annual Installation & Maintenance Costs		Accumulative Costs for Energy, Installation & Maintenance	
Year	Incandescent	LED	Incandescent	LED	Incandescent	LED
1	$1,564.67	$743.86	$34,884	$42,500	$36,449	$43,244
2	$1,519.10	$722.20	$5,903	$311	$43,871	$44,277
3	$1,474.85	$701.16	$5,731	$302	$51,077	$45,280
4	$1,431.89	$680.74	$5,564	$293	$58,072	$46,253
5	$1,390.19	$660.91	$5,402	$284	$64,865	$47,198
6	$1,349.70	$641.66	$5,245	$276	$71,459	$48,116
7	$1,310.39	$622.97	$5,092	$268	$77,861	$49,007
8	$1,272.22	$604.83	$4,944	$260	$84,077	$49,872
9	$1,235.16	$587.21	$4,800	$253	$90,112	$50,712
10	$1,199.19	$570.11	$4,660	$245	$95,971	$51,527
11	$1,164.26	$553.50	$4,524	$238	$101,659	$52,319
12	$1,130.35	$537.38	$4,392	$231	$107,182	$53,087
13	$1,097.43	$521.73	$4,264	$224	$112,544	$53,834
14	$1,065.46	$506.54	$4,140	$218	$117,749	$54,558
15	$1,034.43	$491.78	$4,020	$212	$122,803	$55,261
16	$1,004.30	$477.46	$3,903	$205	$127,710	$55,944
17	$975.05	$463.55	$3,789	$199	$132,474	$56,607
18	$946.65	$450.05	$3,678	$194	$137,099	$57,251
19	$919.08	$436.94	$3,571	$188	$141,590	$57,876
20	$892.31	$424.22	$3,467	$182	$145,949	$58,482
21	$866.32	$411.86	$3,366	$177	$150,182	$59,071
22	$841.09	$399.86	$3,268	$172	$154,291	$59,643
23	$816.59	$388.22	$3,173	$167	$158,281	$60,199
24	$792.80	$376.91	$3,081	$162	$162,155	$60,738
25	$769.71	$365.93	$2,991	$157	$165,915	$61,261

EVALUATIONS

Data collected from illumination measurements as well as visual observation (documented with photo imagery) verified that the LED taxiway luminaire tested provided substantially better performance than the base existing incandescent taxiway luminaires. The LED provided higher illumination as measured by illuminance readings. More importantly however, visual brightness of the LED test luminaire was superior to that of the incandescent base. This characteristic is especially important with wayfarer lighting such as that used for airport taxiways. It is also important to note that the increased visual performance of the LED was achieved by a luminaire with significantly lower power consumption than the incandescent lighting. The more intense blue color of the LED luminaires also contributes to the visual impact and perception of the LED luminaires versus the incandescent base luminaires.

Superior performance characteristics of the LED taxiway luminaire tested are itemized as follows in Table 4.

TABLE 4. PERFORMANCE CHARACTERISTIC COMPARISONS

PERFORMANCE FACTOR	INCANDESCENT (BASE LUMINAIRE)	LED (TEST MODEL)	LED PERFORMANCE IMPROVEMENT *1
Light output (avg. Illuminance) *2	0.112 fc	0.139 fc	25% higher at Level 3
Uniformity (min. to max.) *3	7.2 : 1	5.2 : 1	Improved 28% at Level 3
Visual acuity (visual brightness) *4	Close In: 1/15 Far Out: 1/50	Close In 1/30 Far Out: 1/50	Brightness of LED allowed for three stops faster shutter
Rated power density of luminaire	45W	10W	35W less power per luminaire (78% reduction)
Rated lamp life	1,000 hrs	50,000 hrs	50 times longer lamp life

*1: Performance improvements shown on this chart based on Level 3 full light output operation
*2: Illuminance as measured off 2-foot X 3-foot white board test surface
*3: As calculated from minimum and maximum illuminance recorded on white board test surface
*4: As observed and recorded by digital images. LED's significantly higher surface brightness
Allowed for capture of equally bright images with three stops faster shutter speed than incandescent on reference photos

RECOMMENDATIONS

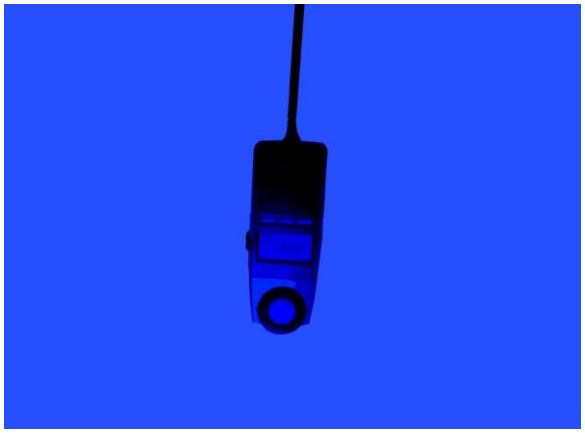
The LED taxiway luminaire tested demonstrated its ability to provide superior way finding illumination at significantly lower power consumption than conventional incandescent taxiway luminaires. The substantially longer LED lamp life will also significantly reduce re-lamping maintenance.

LED luminaire technology is well suited for and should be encouraged for taxiway illumination:

- The LED light source, rich in blue wavelength light, provides greater visual impact than conventional incandescent lights with blue filters.
- Power consumption is drastically reduced (52.5%) with the LED taxiway lighting system over that of an incandescent system.
- Maintenance is minimized with the extended lamp life of the LED taxiway system.
- Luminaire dirt depreciation is claimed by the manufacturer to be much less than incandescent. The lower temperature of the LED luminaire lens prevents the "baking effect" that causes contaminants to stick to the surface of the lens. The manufacturer's estimate is about 400 °F for the glass of the incandescent and about 100 °F for the LED.

APPENDICES

Additional pictures



Minolta T10 light meter measuring illuminance

Close-up of PAR 56 lamp and blue lens

Incandescent taxiway lamp being removed

Visual impact comparison - LED taxiway luminaire with two adjacent incandescent luminaires

Airport Tower

Electric Building housing airfield lighting panels