COMMERCIAL LED POOL LAMPS

ET10SCE1130 Report

Prepared by:

Design and Engineering Services
Customer Service Business Unit
Southern California Edison

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Acknowledgements

Southern California Edison's Design & Engineering Services (DES) group is responsible for this project. It was developed as part of Southern California Edison's Emerging Technology program under internal project number ET10SCE1130. DES Yun Han conducted this technology evaluation with overall guidance and management from Paul Delaney. For more information on this project, contact *Yun.Han*@sce.com.

Disclaimer

ABBREVIATIONS AND ACRONYMS

AC	Alternating Current
CCT	Correlated Color Temperature
CRI	Color Rendering Index
EE	Energy Efficiency
ET	Emerging Technology
F	Fahrenheit
fc	Foot-candle
HPS	High Pressure Sodium
Hz	Hertz
IESNA	Illuminating Engineering Society of North America
K	Kelvin
kW	kiloWatt
LED	Light Emitting Diode
Lm/W	Lumens per Watt
LPD	Lighting Power Density
LTTC	Lighting Technology Test Center
Lu	Lumens
Lx	Lux
PF	Power Factor
PVC	Polyvinyl Chloride
RMS	Root Mean Square
RTTC	Refrigeration Technology Test Center
THD	Total Harmonic Distortion

SCE	Southern California Edison
TTC	Technology Test Center
UPD	Unit Power Density
V	Volt
W	Watts
WLV	West-Lake Village

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EXECUTIVE SUMMARY

Southern California Edison (SCE) conducted the Commercial Light Emitting Diode (LED) Pool Lamps Emerging Technologies (ET) Assessment Project to determine the energy savings, performance, and merits of LED pool lighting. The project assessed LED lighting to replace the incumbent incandescent lighting used in commercial pools for recreational swimming, amateur athletics, and Jacuzzi spas. The project selected five swimming pools and three Jacuzzi spas in three locations in Southern California to survey and evaluate:

- One recreational pool and one spa at the Hyatt Hotel in Westlake Village, CA
- Two recreational pools and one spa at the Marriott Villas (timeshare), Palm Desert, CA
- Two recreational lap pools and one spa at the Marriott Desert Springs, Palm Desert, CA

All five pools and three spas were first surveyed to map the pools' footprints, specifications of existing lighting, and general characteristics. The data was used to establish the baseline. Existing incandescent lighting within the pools and spas surveyed ranged from 300 Watt (W)/R40 to 500W/R40 120 Volt (V) medium-based socket luminaires.

The replacement technologies selected were equivalent LED screw-in replacement lamps and a dedicated (new) LED pool lighting luminaire, as suggested by the manufacturers. The chosen LED lamps and luminaire were then tested in SCE's Lighting Technology Test Center (LTTC) laboratory to determine their performance. Wattage of the LED lights ranged from 20W to 68W and light output from 729 lumens to over 3,000 lumens per lamp/luminaire.

SIGNIFICANT ENERGY SAVINGS

Typical incandescent pool lighting wattages of 300W, 400W, and 500W presents great potential in saving energy when using LEDs as an alternative source. The project tests have demonstrated that using LED pool lights save between 80% - 94% energy. Depending on the operating hours, the annual kWh savings can range anywhere from 500 to almost 1,100 kWh/yr per lamp.

BETTER VISUAL QUALITY

Visual enhancements from LED pool lights as observed and photographed during testing include:

- Deeper, bluer color that enhances the overall ambiance of the pool
- Improved visual uniformity, less apparent "hot spots" which were prevalent in the baseline pool lighting
- Improved penetration of light (illumination) into the water with LED versus the incandescent base illumination, and
- LED pool lights exhibit the ability to deliver available lumens at greater distances since natural blue filtration, caused by the volume of water, cancels out lumens in the warmer (lower Kelvin range) but allows most of the blue range lumens (prevalent in 5,000 Kelvin (K) – 7,000K) to pass through.

LIMITATIONS

Illumination targets for the project were based on Illuminating Engineering Society of North America (IESNA) criteria as well as California requirements for pool and spa lighting. All the pools measured met the minimum 0.5W per square foot IESNA recommended power density and California Counties and Cities' 0.5W/sq.ft code requirements. However, most of the pools did not meet the IESNA recommended 15 lumens per square foot of pool area. Furthermore, none of the pools in the field test met the IESNA 5 foot-candles (fc) average at pool surface area. Any SCE incentive program for LED pool lighting may want to establish program guidelines that meet IESNA recommended values.

LED lighting as an alternative to existing incandescent pool lighting has great potential to save energy and improve aesthetics. Replacing incandescent wattages ranging from 300-500 Watts with LEDs have potential to save over 80% in energy and up to 1,100 kWh per year. Aesthetics are improved especially for those LED lights with cooler 5,000K to 6,500K color temperatures. There are however, limitations within the crop of current LED pool lighting products that restrict their pool lighting application.

Screw-in retrofit LED pool lights, for the most part, are not available in high lumen packages. Screw-in retrofits at present are suited as a re-lamp option when existing incandescent pool lighting is no more than 300W. Only one screw-in retrofit was able to meet the equivalency of a 300W incandescent pool lamp. Currently, greater potential is available for dedicated LED pool light system replacements. These units are also well suited to new pool construction. Most dedicated LED systems tested exhibit the ability to provide LED lighting equal to or better than standard incandescent pool lighting even at higher 500W existing incandescent luminaire applications.

Results from this project may be used to design energy efficiency (EE) incentive program to promote LED pool lighting. Any such program should carry the following disclaimers:

1. LED pool lamp replacements are recommended only if/when:
    - The LED measure provides equal or greater illumination and illumination ratios than the existing incandescent lighting
    - Existing incandescent lighting (baseline) meets or exceeds IESNA standards and recommendations, where applicable, and the LED replacement is also within approved standards
2. Recommendation of LED pool lamps do not preclude owners and/or designers and contractors from complying with recommended pool lighting standards and all applicable codes, where applicable.

As LED technology matures, existing limitations with respect to their use as retrofit replacements will likely diminish.

INTRODUCTION

The study seeks to analyze performance and effectiveness of LED replacement lamps and LED lighting systems as an alternate to conventional incandescent pool lighting ranging from 300 Watt (W)/R40 to 500W/R40. The study evaluated two LED screw-in retrofit replacement lamps and one dedicated LED lighting system replacement. In addition, the study used five pools and three Jacuzzi/spas as test sites. The five pool test sites included two residential style pools and two lap pools at the Marriott Desert Springs resort and the Villas in Palm Desert, CA, and a leisure style pool at the Hyatt in Westlake Village, CA. Two of the three Jacuzzi/spas were adjacent to pools at the Marriott Desert Springs the a third at the Hyatt Westlake Village (WLV).

EMERGING TECHNOLOGY/PRODUCT

A Light Emitting Diode (LED) pool lamp is an underwater lighting luminaire used to illuminate swimming pools for safety, security, and aesthetics. The LED replaces the incandescent pool lamp traditionally screwed into an airtight fixture that submerges under water. It comes in two different variations: as a fixture replacement and as a screw-in replacement. The fixture replacement requires an entire fixture replacement along with the wiring that runs through an underground conduit, while the screw-in replacement only replaces the incandescent lamp with an LED lamp within the same/existing fixture.

Whether LED or incandescent, the LED pool lamp works by cooling itself with water. The fixture fits inside a niche that is typically three feet below the water level. Although screwed into the niche with one screw, the fixture has holes around the face to let water pass through.

A LED is a semiconductor completely covered in epoxy. It emits light when there is a proper amount of current in the LED. Often used as indicator lights, the small, low-output LED is a mature technology. However, advances in LED technology have made them brighter and more efficient, thereby expanding the application of LEDs to other markets. The operation of the LED pool lamp is the same as that of the incandescent pool lamp from the perspective of the end-user.

Incandescent pool lamps' common wattages found in the field are 300W, 400W, and 500 Watts and rated to last about 2,000 hours. LED pool lamps range from 26 - 67 Watts and can have comparable light output of up to 3,000 lumens with a 50,000+ hour life. Longer life reduces the maintenance cost and the risk of wearing down the fixture by opening it multiple times.

Aesthetics is another improvement compared to incandescent lamps with a color temperature of 3,000 Kelvin (K). LED pool lamps have color temperatures ranging from 4,500K to 7,000K that can blend very well with the bluish plaster in most pools. Incandescent lighting in a pool visually shows a yellow glow around the lamp with poor light distribution.

Cost is a big market barrier with LED pool lamps. Each lamp can cost from $300 up to $600, which can be as much as 30 times the cost of the incandescent pool lamps. Although the first cost of the LED technology is high, it saves up to 94% energy, resulting in a possible simple payback of two years. For an 11-year lifecycle of the LED systems, it can save on operating costs by as much as six times that of the incandescent.

GOALS AND OBJECTIVES

The objectives of the project are to:

- Determine the ability of LED retrofit lamps and LED lighting systems to illuminate swimming pools effectively.
- Determine potential energy reduction using current state LED technologies to replace traditional 300W - 500W incandescent pool lighting.
- Establish levels of equivalent LED illumination needed to adequately light swimming pools with equal or better performance compared to baseline incandescent lighting.
- Compare performance distribution of LED lighting versus traditional incandescent lighting for in-pool lighting applications.
- Evaluate and document visual characteristics of LED pool lighting versus baseline incandescent pool lighting.
- Document findings and provide recommendations.

TECHNOLOGY/PRODUCT EVALUATION

Testing of the LED and incandescent pool lamps occurred in the field and in the laboratory. The field test is required to compare footcandle levels from the measure (LED) to the baseline (incandescent) in a real-world environment. Water and temperature in the field are variables that cannot easily be simulated in the lab for direct comparison of light characteristics. Laboratory testing was required to determine the photometric and power data such as total lumen output, Correlated Color Temperature (CCT), Watts (W), and Power Factor (PF).

Field-testing occurred in three different hotels with Jacuzzi/spas at each site. Quantifying the light levels in a pool is independent of the pool's geographical location. Laboratory testing occurred in-house at SCE's Technology Test Center (TTC) located in Irwindale, CA.

The criteria of the test site for field assessment are to capture the typical pool lamp wattages of 300, 400, and 500 Watts. The shape of the pool is not significant to the test since the tested LED lamp was relative to the performance of the incandescent lamp within the same pool.

An outside contractor performed the field assessment. The contractor has extensive knowledge in testing various LED technologies including but not limited to LED street lights and LED area lighting.

Table 1 shows the five tested lamps. The report uses this naming convention throughout. Appendix D shows the lamp images.

TABLE 1. REFERENCE OF TESTED LAMPS

NAME	TYPE	WATTS
LED Luminaire A	Screw-in	25.8
LED Luminaire B	Screw-in	49.4
LED Luminaire C	Whole Fixture Replacement	42.1
LED Luminaire D	Whole Fixture Replacement	52.4
LED Luminaire E	Whole Fixture Replacement	67.4

TECHNICAL APPROACH/TEST METHODOLOGY

FIELD TESTING OF TECHNOLOGY

The field assessment consists of vertical illuminance and horizontal illuminance fc readings taken within each of the test pools and spas. Vertical fc measurements were recorded around the perimeter of the pools and spas. Vertical measurements were taken approximately 2-feet below the surface of the pools and 1-foot below the surface of the spas. Horizontal fc readings were recorded at the bottom of the pools and spas as well as the steps leading to the pools and spas. Twenty to thirty vertical grid points and five to ten horizontal grid points were recorded at each pool and spa in the test model. The number of grid points selected per site was based on pool/spa size as well as configuration (footprint).

The pool lamp system is the same whether it is for LED or incandescent lamps. It uses the same niche where the fixtures reside and works off the same power line and lighting control. There is a minor difference for LEDs as there are two types: screw-in and whole-fixture replacements. The screw-in LED replacement lamp directly replaces the incandescent lamp without having to replace the fixture. The whole-fixture replacement requires the existing fixture to be completely pulled out of the niche with all the wiring that goes to the junction box. The difference in type of packaging that the LED lamps come in will not affect the overall results.

The existing technology is an R40 incandescent pool lamp rated at 300, 400, and 500 Watts depending on the site. A certified pool contractor performed all the replacements and installations of the pool lamps when required. The installation consists of checking for leaking water inside the fixture and replacing the gaskets for proper air-tight sealing.

The system for both incandescent and LED pool lamps are controlled by a time-clock. Other pools not tested may be manually controlled or use a different type of control such as a photocell.

Operating hours and the water temperature are the only components that are monitored in the field. The lab testing includes all of the necessary power data used to establish energy savings. The temperature loggers were zip-tied to the back of the pool lamp fixture that hid inside the niche when installed. The logging of the operating hours was achieved by placing a logger at the time-clock, measuring the kilo-Watt hour (kWh) consumption.

Temperature is monitored only for the LED pool lamps to determine the effects of light output based on water temperature. Temperature is monitored during summer time to capture the hot days as the pools are typically heated to 82°F while cool temperature has no significance to light output. The operating hours for each site is captured with no specific period since the test sites use time clocks to turn the pool lights on and off.

The data from the loggers were downloaded only once since the testing did not require long-term logging. The operating hours were logged in 1-minute intervals for one month to verify the operation of the time clock. The water temperatures of the 80° heated pools were logged in 2-minute intervals for one month. There is no rapid

change in temperature of the water and the overall temperature of the pool at a given time that it did not require shorter interval logging of data.

LAB TESTING OF TECHNOLOGY

The laboratory evaluations consist of a two-part test. The integrating sphere test measures photometric and power characteristics of the LED pool lamps, while the temperature dependency test measures the dependency of the luminaires' light output with respect to temperature.

Testing was conducted at SCE's Technology Test Centers (TTC). See Appendix A for additional information on these facilities.

PHOTOMETRIC TESTING

The photometric testing was conducted using an integrating sphere described in the Equipment section of Appendix B. Figure 1 shows the mounting system in the integrating sphere.

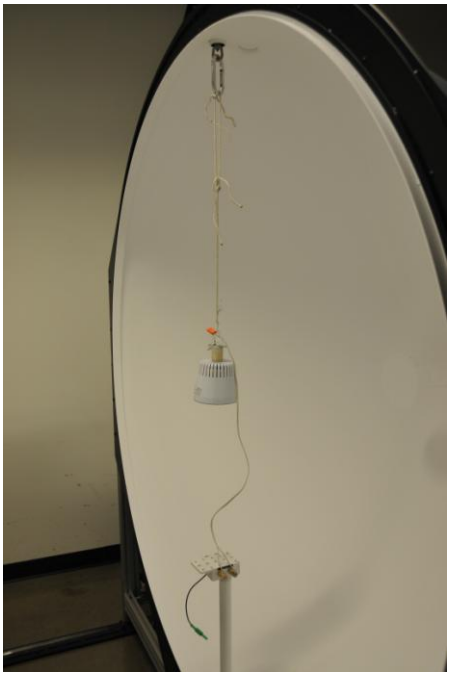


FIGURE 1. LUMINAIRE SETUP IN INTEGRATING SPHERE

TEMPERATURE DEPENDENCY TEST

The thermal testing consists of measuring the relative light output and electrical demand for each fixture under varying temperatures. This test was conducted using a bucket of water and a submerged pool light fixture facing up as shown in Figure 2 in an isolated room with no light shining through. The water temperature started at 60°F and increased to 80°F at 10°F intervals, and lowered back to 70°F.

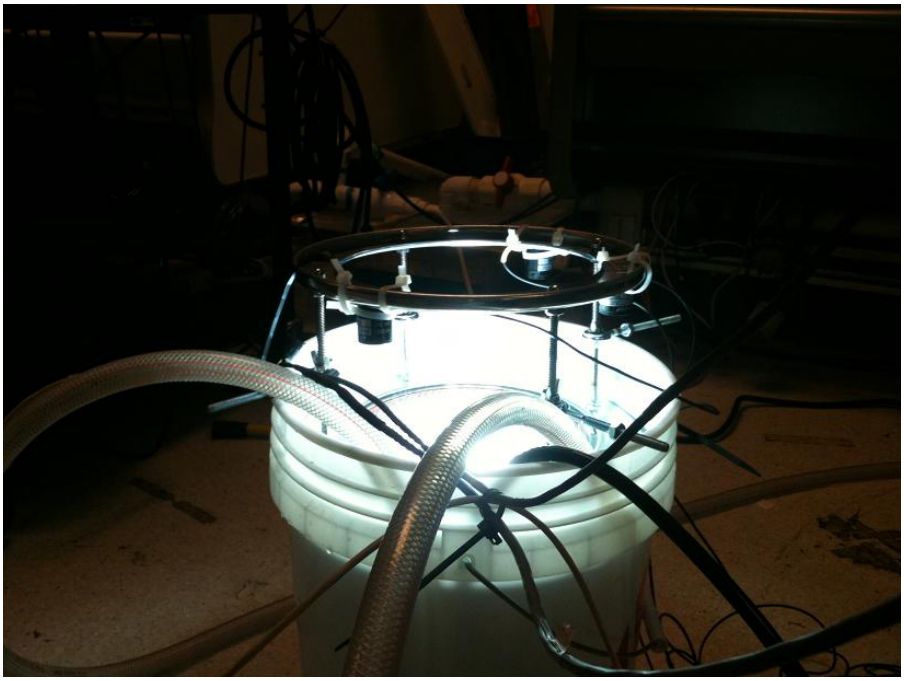


FIGURE 2. LUMINAIRE SETUP IN A BUCKET

PROCEDURE

- First, the water is stabilized at a given temperature within 1°F, at the following temperatures: 60°F, 70°F, and 80°F.
- Second, the fixture is allowed to reach stability as determined by the variation of the readings as defined in Equation 1 (adapted from IES LM-79-08 as described in the Equipment section under Integrating Sphere).

EQUATION 1. VARIATION EQUATION

$$\left(\frac{V_{high}-V_{low}}{V_{last}}\right)100 < 0.5\%$$

Where:

Readings are taken at 15-minute intervals.

V_{high} = highest value from last three consecutive readings taken at 15 minute intervals

V_{low} = lowest value from last three consecutive readings taken at 15 minute intervals

V_{last} = latest reading

If the variation of the equation is less than 0.5% for both light and electrical demand, the fixture is assumed stable and final readings are taken for that temperature.

- Third, the process is repeated for the next temperature.

FIELD TEST PLAN

ESTABLISHING ILLUMINATION TARGETS

Illumination targets were initially based on IESNA criteria as well as California requirements for pool/spa lighting. These requirements were found to be limited in scope. Therefore, while this data is included in the report, default targets were established via measurements of existing incandescent lighting in each of the pools/spas evaluated.

IESNA POOL LIGHTING CRITERIA

SPORT & RECREATIONAL LIGHTING CLASSIFICATIONS

Class I Competition (Audience of 10,000 or less)
Note: Audiences greater than 10,000, or use of TV equipment, frequently requires horizontal and vertical levels more than double standard Class I levels.

Class II Competition (Audience less than 5,000)

Class III Competition (Primarily for players & small audience)

Class IV Social and Recreational Play

TABLE 2. RECOMMENDED LAMP LUMENS FOR UNDERWATER LIGHTING

Class	*APPLICATION*	*PER SQ. FT. POOL SURFACE AREA*		**UNIFORMITY** (MAX. TO MIN)
		Indoor	**Outdoor**	2.0
I	International, Professional & Tournament	100	60	2.5
II	College & Diving	75	50	3.0
III	High School without Diving	50	30	4.0
IV	Recreational	30	15	2.0

TABLE 3. RECOMMENDED ILLUMINANCE CRITERIA FOR ABOVE-POOL LIGHTING

Class	Surface in Horizontal Foot-candles			Vertical Foot-candles	UNIFORMITY (MAX. TO MIN.)
	Indoor	Outdoor	Deck	*PLATFORM*	
I	70	-------	50	70*	2.0
II	50	30	20	30	2.5
III	30	20	10	-------	3.0
IV	30	10	10	-------	4.0

* The platform in the principal viewing direction should have 70 to 100 fc's without direct glare to the divers.

(Note, that illuminance recommendations shown for above pool lighting pertain to pools used for water sports activities, not recreational leisure pool sites and area lighting.)

Control of glare is critical when lighting any swimming pool. Specular surfaces such as swimming pools can cause reflected glare that reduces the ability of the lifeguard to see beneath the surface or even some objects on the surface of the water.

Vertical illuminance for multidirectional sports such as swimming must also be taken into consideration. The ratio of this illuminance at ground level is also important and should be less than 3:1 between the horizontal and vertical planes as well as between vertical illuminance in the four primary viewing directions.

TABLE 4. RECOMMENDED LUMINANCE'S FOR POOL SURFACE AREA

CLASS	CANDELAS PER SQ. FT. OF POOL SURFACE AREA	
	Indoor	Outdoor
I	35	-------
II	25	15
III	15	10
IV	15	5

(Luminance recommendations primarily apply to pools used for water sports activities, not recreational leisure.)

RECOMMENDED UNIT POWER DENSITY (UPD) FOR POOL SURFACE AREA

(UPD recommendations primarily apply to pools used for water sports activities, not recreational leisure pools.)

Underwater illumination may be produced from luminaires directly over the water and by underwater luminaires. As a rule, UPD required for underwater lights varies between 5 to 30W per square meter (0.5 to 3W/sq ft) of water surface depending on the class of facility and efficacy of light sources.

Typical Code pool lighting criteria and requirements

UPD required for underwater lights by California counties and cities: 0.5W per sq ft of pool surface (incandescent luminaires or alternate equivalent light source).

Default Targets via measurement of existing incandescent pool lighting

- Range of vertical illuminance for base incandescent pool lighting: 0.94 to 3.13 fc
- Range of horizontal illuminance for base incandescent pool lighting: 0.74 to 3.11 fc
- Range of vertical illuminance for base incandescent Jacuzzi lighting: 9.49 to 12.42 fc
- Range of horizontal illuminance for base incandescent pool lighting: 4.81 to 32.17 fc

Note: Default targets are for comparison of existing incandescent lighting recorded at the test pools versus the measured alternate LED lighting options. These targets are not representative of illuminations criteria only actual base lighting at the test sites.

Lab Test Plan

The integrating sphere testing was performed in accordance with the "IES Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products" (IES LM-79-08), excluding section "2.2 Air Temperature". LM-79-08 requires ambient air temperatures be maintained at 25 centigrade (77°F), plus or minus 1 centigrade, as measured 1 meter from the product and at the same height as the product. In actual testing, ambient temperature was not maintained at 25 centigrade, but was monitored throughout the test. The Thermal Dependency test was performed using the same method as the integrating sphere test, adapting from the IES LM-79-08.

Variables

Illuminance

Illuminance is the measure of the intensity of the incident light on a surface in a given area, provided in lux (lx). For the field testing portion, the measurements are taken in foot-candles, which is a non-metric unit of illumination. One fc is equal to approximately 10.764 lx.

Light Output

Light output is the measure of light that a source provides, measured in lumens. Lumen output data was obtained from the integrating sphere test discussed in the Equipment section.

Color Rendering Index

Color rending index (CRI) is a quantitative measure that describes how well a light source renders color compared to a reference light source of similar color temperature. This index is scaled from 0-100.

The color quality, measured as CRI, affects visual perception. The CRI is directly related to the colors or spectral characteristics that the lamp produces. CRI data is obtained from the integrating sphere test discussed in the Lab Equipment section.

CORRELATED COLOR TEMPERATURE

Correlated color temperature (CCT) indicates whether a white light source appears more yellow/gold or blue, in terms of the range of available shades of white. CCT is derived by a theoretical object in physics, referred to as a "black body" that absorbs all electromagnetic radiation. When heated to high temperatures this object emits different colors of light based on the exact temperature. Hence, the CCT of a light source is the temperature (in Kelvin) at which the heated black body matches the color of the light source in question. The "hotter" (higher Kelvin) the more blue in appearance, the "cooler" (lower Kelvin) the more red in appearance. CCT data is obtained from the integrating sphere test, discussed below, and is compared to the manufacturer's CCT ratings.

CONNECTED LOAD

Power requirements for all test cases are determined by measuring current and voltage. Measurements for both are taken between the driver and power source to understand alternate current (AC) power. This information is used to understand demand (kW) savings of the measure cases when compared to the baseline cases.

EFFICACY

An important indication of overall lamp performance is efficacy. This value, in lumens per watt (lm/W), is a measure of light output over power input. A higher efficacy lamp provides more lumens of light output per watt than a lower one. Though LED wattage may be lower than their fluorescent counterpart, it must do so while providing the same amount of light. A lamp with a higher efficacy has the most energy savings potential.

INSTRUMENTATION PLAN

EQUIPMENT

The assessment used several pieces of equipment and each piece is described in the following sections. For additional information and technical specifications, see Appendix B.

LIGHT METER

The light meter used for illuminance measurements of both baseline (incandescent) and LED illumination in the field is a Minolta T10 with 10-meter waterproof cable and mini sensor as shown in Figure 3. Certified calibration assures meter accuracy within 1.5% at measured low light levels of 5 fc down to 0.1 fc (50 to 1 Lx).

FIGURE 3. MINOLTA T10 LIGHT METER WITH WATERPROOF CABLE AND SENSOR

Custom outriggers and skimmers for attaching the meter cable and sensor were designed and fabricated using standard ½-inch polyvinyl chloride (PVC) pipe. Pipe sections are adjustable in length as well as angle and directions. Use of this fabricated device assured that sensor placement was consistent for both vertical and horizontal meter measurements during the entire evaluation process. Figure 4 is a photograph of the PVC pipe jig constructed to deliver the meter sensor to underwater measuring points within the pools.

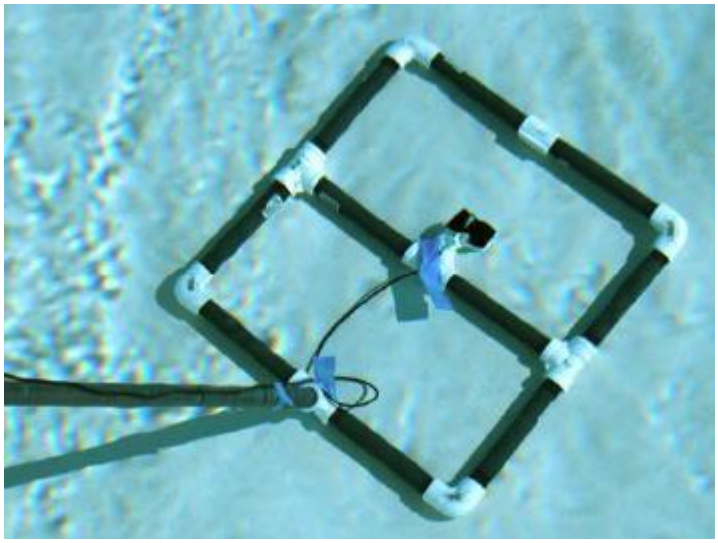


FIGURE 4. MINI SENSOR ON PVC SKIMMER FLOATING

Integrating Sphere

The integrating sphere measures the total light output of a light source. This can be a lamp or a complete luminaire. The tested light source is placed in the center of the integrating sphere. At one side of the sphere is a light meter that measures the light output from the light source. A baffle is directly between the source and the light meter to prevent the meter from seeing any direct light from the source. This equipment is used to measure the light output of a light source, the CRI, and CCT. The temperature is regulated to approximately 77°F. Measurements are taken every 15 minutes until three consecutive measurements are within 0.5% of each other.

The entire inside of the sphere (including the baffle and mounting for the lamps) is coated with a highly reflective white paint that reflects all wavelengths equally. This allows for accurate measurements. The calibrated power supply is connected to the lamp wiring on the outside of the sphere. Readings from the optical sensor are processed with the integrated software and displayed on the monitor.

Figure 5. Integrating Sphere

Light Logging System

Illuminance (lx) of the lab testing portion is measured with three LI-COR LI-210 photometric sensors connected to a LI-COR LI-1400 handheld data logger. The sensors are positioned directly above the fixture on the modified face ring for the pool lamps.

Chiller System

The temperature of the water is adjusted using the two-gallon PolyScience Recirculating Chiller to adjust the temperature between 60-80°F for the lab test. The hoses are placed at the very bottom of the water bucket away from the thermocouple.

Laboratory Temperature Logging System

Temperature (°F) of the chilled water is measured with one thermocouple positioned inside the water bucket. The thermocouple is monitored and logged using a National Instruments data acquisition system installed for the controlled environment room. Readings are logged every 10 seconds.

Power Quality Analyzer

Voltage (V) root mean square (rms), current in amperes (A), power in Watts (W), frequency Hertz (Hz), power factor (PF), and current total harmonic distortion (THD) (%) are measured with a Hioki 3196 Power Quality Analyzer. Readings are logged every 10 seconds, and manually monitored every 15 minutes for stability during the controlled environment room testing.

Operating Hour Logger

The operating hours of the pools were recorded using the Micro Data Logger (MDL) Model 202. This logger is intended to log the kW and kWh, but instead is used to verify only the operating hours of the site.

Water Temperature Logger

Pool water temperature in the field is measured in °F with the Hobo U22 Water Temp Pro v2 logger. Readings are logged every 1 minute and downloaded via the Hobo Shuttle.

LABORATORY MEASUREMENT RESULTS

The laboratory evaluations tested all five lamps/luminaires used in the field in the integrating sphere test. Due to the design and application of both screw-in and whole-fixture replacements, all of the lamps/luminaires were tested in the laboratory for their photometric data to be used in conjunction with the field measurement data.

Two of the luminaires B and E were tested in the temperature dependency test. Not all of the lamps tested in the field required this testing as the objective of this test is to confirm that the light output is dependent on temperature.

PHOTOMETRIC AND POWER DATA (SPHERE TEST)

Table 5 shows a summary of measured values for the five lamps/luminaires.

TABLE 5. INTEGRATING SPHERE TEST RESULTS FOR LUMINAIRES

LUMINAIRE	LUMINOUS FLUX (LUMENS)	CCT (KELVIN)	CRI	POWER (W)	EFFICACY (LUMENS/WATT)
LED Luminaire A	729	4,508	67	25.8	28.2
LED Luminaire B	1,917	6,626	75	49.4	38.8
LED Luminaire C	2,353	6,676	71	42.1	55.9
LED Luminaire D	2,732	7,039	73	52.4	52.1
LED Luminaire E	3,039	6,647	72	67.4	45.1
300W Incandescent	2,092	2,582	99	273.0	7.7
400W Incandescent	3,201	2,582	99	406.4	7.9
500W Incandescent	4,573	2,673	99	472.4	9.7

TEMPERATURE-DEPENDENCY DATA

Figure 6 shows the effects of temperature on light output. The pools used in the field-testing were heated to 80°F throughout the day. Therefore, the range of the temperature-dependency test was limited to 80°F.

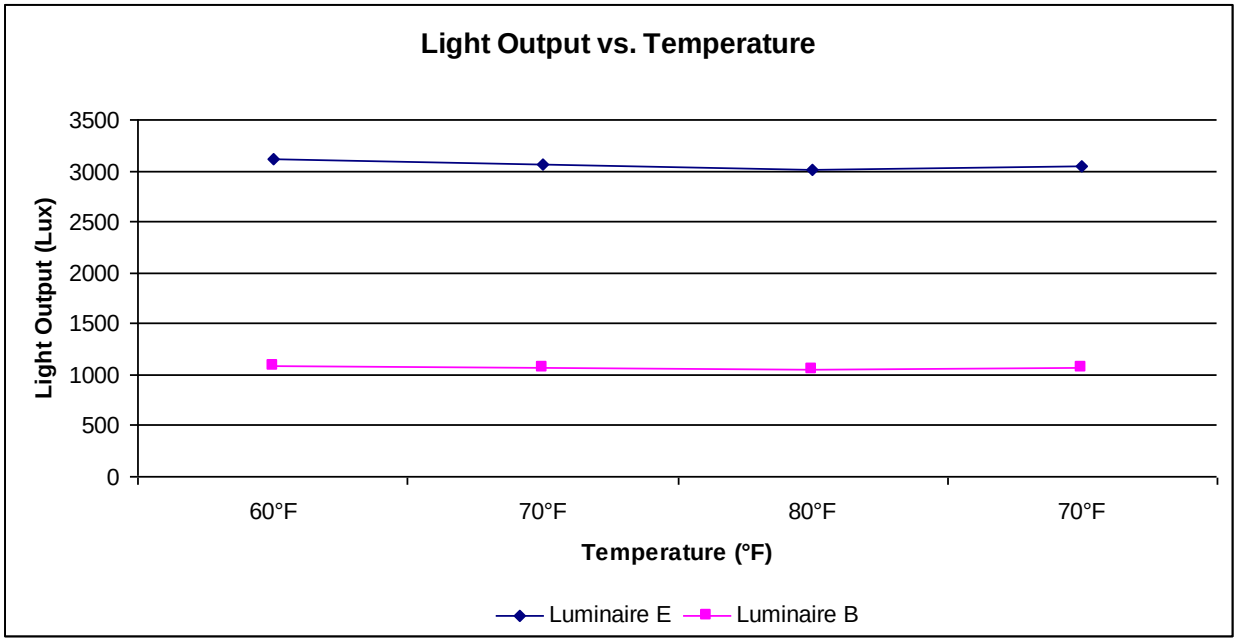


FIGURE 6. LIGHT OUTPUT TEMPERATURE DEPENDENCY

Figure 6 indicates that the light output decreases linearly as the temperature increases and vice versa. Table 6 shows the actual numbers for each temperature measurements.

TABLE 6. LABORATORY FOOTCANDLE READINGS

TEMPERATURE (°F)	LED LUMINAIRE E (FC)	LED LUMINAIRE B (FC)
60	3119	1080
70	3063	1066
80	3004	1051
70	3039	1062

FIELD MEASUREMENT RESULTS

Nighttime lighting measurements, recorded in foot-candles, were taken for each of the pools and Jacuzzi/spas within the designated test sites. Both base lighting (incandescent) and alternate LED pool lighting were recorded for the pools/spas at each site.

Primary measurements recorded were for in-pool illumination both at the perimeter of the pools and spas as well as selected zones at the bottom of pools and entry steps into the pools and spas. Several additional site area measurements for lighting adjacent to the pools and spas were also documented as part of the survey.

The recording documentation within this section of the report is given for each of the pools and spas. Lighting measurements are recorded on the pool/spa maps that were created as part of the daytime survey. The tables accompanying each on site nighttime measurement includes data extracted from calculations using Excel spread sheets. Incandescent base lighting, LED alternate lighting, as well as statistical documentation and base standards for each pool display in the adjacent tables to the pool maps for each survey. The pool survey summary is shown in Table 7. The full survey with results can be found in Appendix C.

TABLE 7. SUMMARY OF RESULTS

LOCATION	MEASUREMENT	INCANDESCENT (FC)	LED (FC)
Hyatt Westlake Village Pool – LED Luminaire E	Average Vertical	1.66	3.20
	Average Horizontal	0.74	1.31
Hyatt Westlake Village Pool – LED Luminaire B	Average Vertical	1.66	1.25
	Average Horizontal	0.74	0.64
Hyatt Westlake Village Jacuzzi – LED Luminaire E	Average Vertical	9.49	6.99
	Average Horizontal	9.80	7.72
Hyatt Westlake Village Jacuzzi – LED Luminaire B	Average Vertical	9.49	3.73
	Average Horizontal	9.80	4.89
Marriott Resort Spa Pool – LED Luminaire C	Average Vertical	3.13	3.61
	Average Horizontal	3.11	3.70
Marriott Resort Spa Jacuzzi – LED Luminaire C	Average Vertical	12.42	7.98
	Average Horizontal	32.17	43.55
Marriott Resort Lap Pool – LED Luminaire B	Average Vertical	1.21	1.27
	Average Horizontal	0.49	0.69
Marriott Villas Cassia Pool – LED Luminaire D	Average Vertical	2.94	3.63
	Average Horizontal	2.30	2.67
Marriott Villas Cassia Jacuzzi – LED Luminaire D	Average Vertical	9.99	7.11
	Average Horizontal	4.81	3.88
Marriott Villas Mesquite Pool – LED Luminaire A	Average Vertical	3.18	0.86
	Average Horizontal	3.07	0.78

COST RESULTS

The cost of incandescent lamps is very inexpensive compared to the LED lamps/luminaires when only replacing the lamp and not the fixture. The fixture remains in the pool while replacing the incandescent lamp. The cost of having the incandescent fixture replaced in case of leaks or deterioration can be expensive. For the purpose of the cost evaluation, retrofit and new installations are evaluated for a fair comparison.

PARTS AND ACCESSORIES COST

Table 8 shows the costs of the luminaires used in the field test along with accessories and labor costs. Note that LED Luminaire A and B are screw-in replacements while LED Luminaire C, D, and E are whole fixture replacements that require more labor to install.

TABLE 8. PARTS AND ACCESSORIES COSTS

PART	COST	UNIT	LIFE (HRS)
LED Luminaire A	$318.99	lamp	20,000
LED Luminaire B	$592.00	lamp	50,000
LED Luminaire C	$624.99	fixture	50,000
LED Luminaire D	$624.99	fixture	50,000
LED Luminaire E	$624.99	fixture	50,000
Gasket	$16.11	gasket	NA
300W Incandescent	$9.04	lamp	2,000
400W Incandescent	$8.26	lamp	2,000
500W Incandescent	$8.26	lamp	2,000
Incandescent Lamp Fixture	$213.51	Fixture	NA
Labor	$65.00	hour	NA

The gasket is required on all screw-in replacements, for both incandescent and LED lamps. When the fixture opens to replace the lamps inside, you must replace the gasket every time to ensure that no water or moisture seeps through. The labor cost is for general work performed by the certified pool contractor on either replacement technologies.

ENERGY SAVINGS RESULTS

One of the benefits that LEDs have over incandescent technology is energy efficiency. Most pools have 300W incandescent lamps or higher that can give LEDs a huge potential in saving energy.

DEMAND, OPERATING HOURS, & SAVINGS DATA

Table 9 shows the total base and measure wattages with operating hours per site. The operating hours and demand reduction will determine the energy savings.

TABLE 9. DEMAND AND OPERATING HOUR DATA

	Total Base Wattage (W)	Measure Description	Total LED Measure Wattage	Daily Operating Hours	Annual Operating Hours	Wattage Difference (W)
Hyatt Pool	944.8	LED Luminaire B	98.8	4	1460	846
Hyatt Pool	944.8	LED Luminaire E	134.8	4	1460	810
Hyatt Jacuzzi	472.4	LED Luminaire B	49.4	4	1460	423
Hyatt Jacuzzi	472.4	LED Luminaire E	67.4	4	1460	405
Marriott Villas Mesquite Pool	812.8	LED Luminaire A	51.6	4	1460	761.2
Marriott Villas Cassia Pool	812.8	LED Luminaire D	104.8	4	1460	708
Marriott Villas Cassia Jacuzzi	406.4	LED Luminaire D	52.4	4	1460	354
Marriott Resort Spa Pool	1638	LED Luminaire C	252.6	13	4745	1385.4
Marriott Resort Lap Pool	819	LED Luminaire B	148.2	13	4745	670.8
Marriott Resort Spa Jacuzzi	273	LED Luminaire C	42.1	13	4745	230.9

LABORATORY DATA EVALUATION

PHOTOMETRIC DATA

Overall, the efficacies of LED lamps are much higher than the incandescent lamps, as expected. Luminaire E with output of 3,039 lumens is designed to replace a 500W incandescent with 4,573 lumens. The field measurements will be evaluated to confirm the laboratory data.

TABLE 10. INTEGRATING SPHERE TEST RESULTS FOR LUMINAIRES

LUMINAIRE	LUMINOUS FLUX (LUMENS)	CCT (KELVIN)	CRI	POWER (W)	EFFICACY (LUMENS/WATT)
LED Luminaire E	3,039	6,647	72	67.4	45.1
500W Incandescent	4,573	2,673	99	472.4	9.7

The difference in color temperature of the incandescent and the LED is significantly high. The Field Measurement Evaluation section of this report explains the effect of the different color temperatures.

TEMPERATURE-DEPENDENCY DATA

Figure 7 shows the percent light loss due to temperature from the initial stabilization point of 60°F. Maximum light loss of 4% at the peak temperature does not indicate any potential of having insufficient light in the pool during a hot night. Although the test does show that there is a 0.75% loss going from 70°F back down to 70°F, it is within the 1% tolerance of the sensors. This test indicates that there is no permanent light degradation once the LEDs reach a certain percentage of light loss. Each temperature measurement took three readings in 15-minute intervals for it to stabilize.

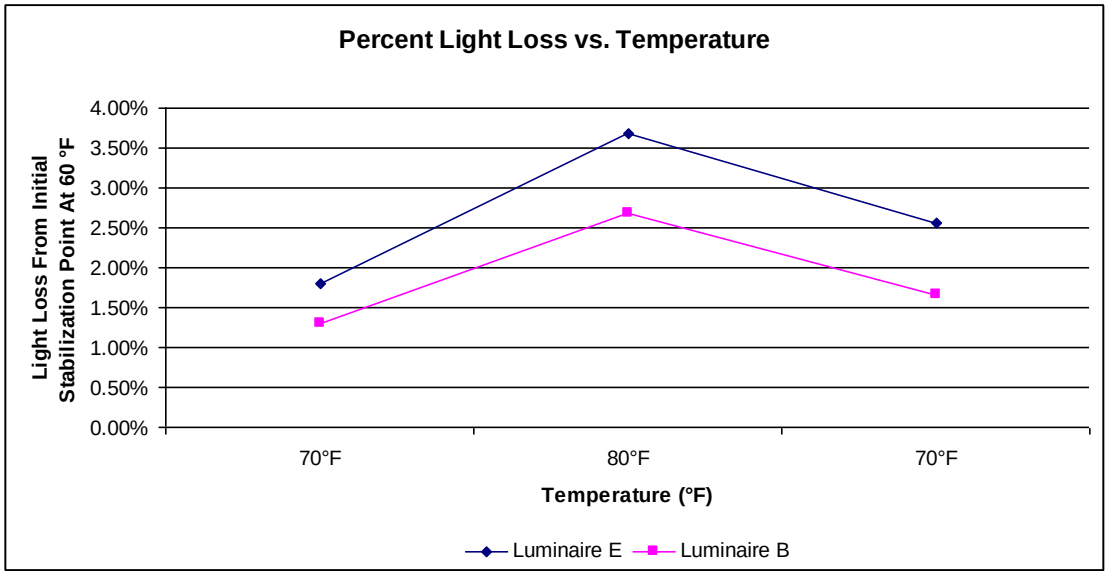


FIGURE 7. PERCENT LIGHT LOSS DUE TO TEMPERATURE

FIELD DATA EVALUATION

In addition to recording nighttime lighting measurements, photographs documenting visual differences between the incandescent and the LED pool lighting were taken for each of the pools and Jacuzzi/spas within the designated test sites. These comparison photographs are included as part of the field data evaluation.

The field data evaluation includes reviews of the pools/spas LPD, and whether it complies with the minimum acceptable base lighting LPD's, as defined by code. Furthermore, lighting uniformity of the base incandescent internal pool lighting is compared to the LED alternates tested at each of the pools and/or spas.

Finally, included in the field data evaluation are analyses of both observed and measured anomalies with respect to this pool lighting study. The anomalies addressed include variations in illumination between pools as well as incandescent versus LED illumination. The effects of water on the in-pool lighting is also covered as is the variations between the dedicated LED system and LED screw-in retrofit LED lighting options.

VISUAL DIFFERENCES - INCANDESCENT AND LED LIGHTING

Visual appearance of each test pool and Jacuzzi spa in the test model was recorded on digital media using a Canon D450 Digital SLR camera with adjustable, 16 mm – 135 mm multi-focal length, digital IS Canon lens. The images within this section of the report depict color and intensity variation, and uniformity between the base incandescent lighting on the tested LED options. Some pictures may not represent the intensity variation very well compared to how it is seen in person and what the instrument measured.

Images are organized by pool and/or Jacuzzi/spa location as well as incandescent versus LED lighting at each location. Evaluation comments and remarks accompany the images. The pictures shown

Hyatt Westlake Village Pool and Spa

Hyatt Westlake Village Pool

Incandescent base illumination – Two 500W Incandescent R40 lamps.

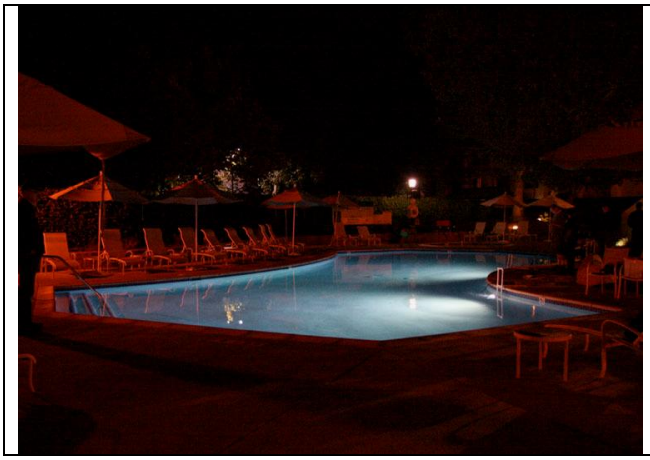
Average vertical illumination of 1.66 fc and horizontal illumination of 0.74 fc.

Hyatt Westlake Village Pool

LED Luminaire E LED illumination – Two 71W proprietary LED light modules.

Average vertical illumination of 3.20 fc and horizontal illumination of 1.31 fc.

LED Luminaire E LED system appears both brighter and exhibits visually improved uniformity. Test measurements confirmed visual observations.



HYATT Westlake Village Pool

LED Luminaire B LED retrofit illumination – Two 42W LED retrofit R40 lamps.

Average vertical illumination of 1.25 fc and horizontal illumination of 0.64 fc.

LED Luminaire B LED retrofit R40 lamps appear equally bright to the incandescent base illumination with visually improved uniformity. Test measurements confirmed improved uniformity and light levels within 75% - 80% of the incandescent base lighting.

Hyatt Westlake Village Jacuzzi Spa

Incandescent base illumination – One 500W incandescent R40 lamp.

Average vertical illumination of 9.49 fc and horizontal illumination of 9.80 fc.

Hyatt Westlake Village Jacuzzi Spa

LED Luminaire E LED illumination – One 71W proprietary LED light module.

Average vertical illumination of 6.99 fc and horizontal illumination of 7.72 fc.

LED Luminaire E system appears equally bright with slightly better uniformity. Measurements documented about 25% less illumination. However, uniformity was improved.

Hyatt Westlake Village Jacuzzi Spa

LED Luminaire B LED retrofit illumination – One 42W LED retrofit R40 lamp.

Average vertical illumination of 3.73 fc and horizontal illumination of 4.89 fc.

LED Luminaire B LED retrofit R40 lamp appears almost as bright as the incandescent base illumination. Test measurements confirmed similar uniformity. However light levels were only 50% of the incandescent base lighting.

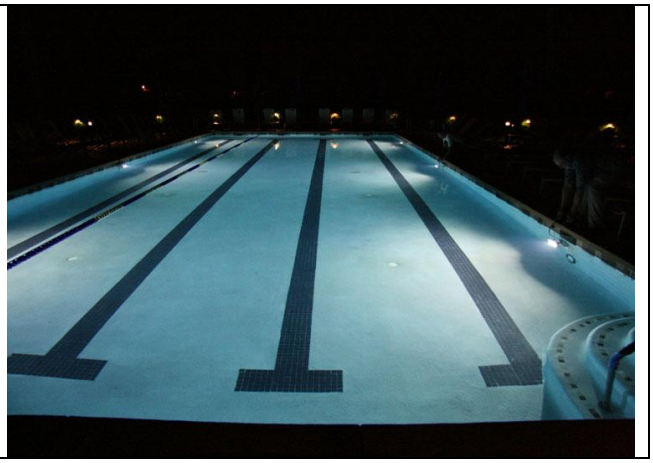
FIGURE 8. HYATT WLV POOL AND JACUZZI – LED LUMINAIRE B AND E

Marriot Desert Springs Resort Spa Pool and Jacuzzi

Marriot Desert Springs Spa Pool

Incandescent base illumination – Six 300W incandescent R40 lamps.

Average vertical illumination of 3.13 fc and horizontal illumination of 3.11 fc.



Marriot Desert Springs Spa Pool

LED Luminaire C LED illumination – Six 54W proprietary LED light modules.

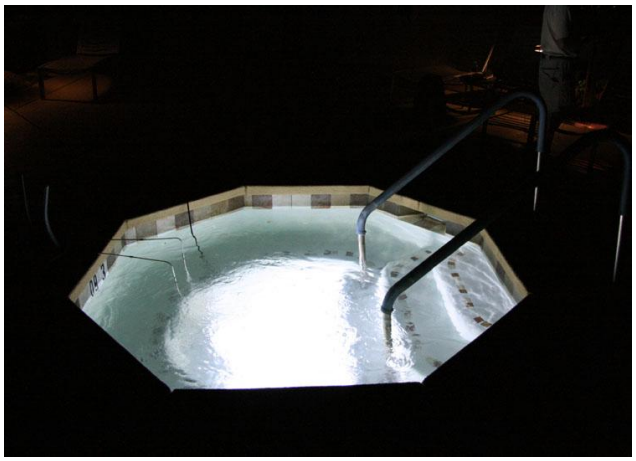
Average vertical illumination of 3.61 fc and horizontal illumination of 3.70 fc.

LED Luminaire C LED system appears both brighter and exhibits visually improved uniformity. Test measurements confirmed visual observations.

Marriot Desert Springs Spa Jacuzzi

Incandescent base illumination – One 300W incandescent R40 lamp.

Average vertical illumination of 12.48 fc and horizontal illumination of 32.17 fc.



Marriot Desert Springs Spa Jacuzzi

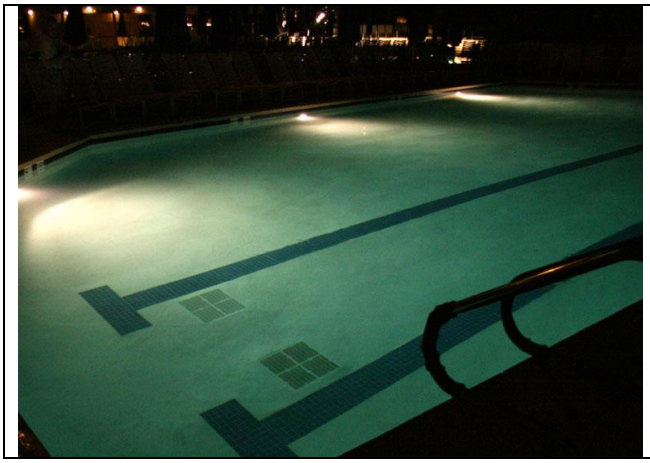
LED Luminaire C LED illumination – One 54W proprietary LED light modules.

Average vertical illumination of 7.98 fc and horizontal illumination of 43.55 fc.

LED Luminaire C LED system appears brighter and exhibits visually improved uniformity. Test measurements confirmed visual observations.

FIGURE 9. MARRIOTT DESERT SPRINGS RESORT SPA POOL AND JACUZZI – LED LUMINAIRE C

Marriot Desert Springs Resort Lap Pool



Marriot Desert Springs Resort Lap Pool

Incandescent base illumination – Three 300W incandescent R40 lamps.

Average vertical illumination of 0.94 fc and horizontal illumination of 0.78 fc.

Marriot Desert Springs Resort Lap Pool

LED Luminaire B LED retrofit illumination – Three 42W LED retrofit R40 lamps.

Average vertical illumination of 1.27 fc and horizontal illumination of 0.69 fc.

J&J LED retrofits measured performance is about the same as the incandescent. However, visually lighting quality appears greatly improved versus the incandescent.

FIGURE 10. MARRIOTT DESERT SPRINGS RESORT LAP POOL – LED LUMINAIRE B

Marriot Desert Springs Villas Cassia Pool and Spa

Marriot Desert Springs Villas Cassia Pool

Incandescent base illumination – Two 400W incandescent R40 lamps.

Average vertical illumination of 0.94 fc and horizontal illumination of 0.78 fc.

Marriot Desert Springs Villas Cassia Pool

LED Luminaire D LED illumination – Two 54W proprietary LED light modules.

Average vertical illumination of 3.61 fc and horizontal illumination of 3.70 fc

LED Luminaire D LED system appears both brighter and exhibits visually improved uniformity. Test

measurements confirmed visual observations.

Marriot Desert Springs Villas Cassia Spa

Incandescent base illumination – One 400W incandescent R40 lamp.

Average vertical illumination of 12.48 fc and horizontal illumination of 32.17 fc.

Marriot Desert Springs Villas Cassia Spa

LED Luminaire D LED illumination – One 54W proprietary LED light modules.

Average vertical illumination of 7.98 fc and horizontal illumination of 43.55 fc.

LED Luminaire D LED system appears brighter and exhibits visually improved uniformity. Test measurements confirmed visual observations.

FIGURE 11. MARRIOTT DESERT SPRINGS VILLAS CASSIA POOL AND JACUZZI – LED LUMINAIRE D

Marriot Desert Springs Villas Mesquite Pool

Marriot Desert Springs Villas Mesquite Pool

Incandescent base illumination – Two 400W incandescent R40 lamps.

Average vertical illumination of 3.18 fc and horizontal illumination of 3.07 fc.

Marriot Desert Springs Villas Mesquite Pool

LED Luminaire A retrofit illumination – Two 26W LED retrofit R40 lamp.

Average vertical illumination of 0.86 fc and horizontal illumination of 0.78 fc

LED Luminaire A retrofit lamps used in this test provide insufficient illumination. The pool is visually darker, test measurements confirmed visual observations.

FIGURE 12. MARRIOTT DESERT SPRINGS VILLAS MESQUITE POOL – LED LUMINAIRE A

LIGHTING POWER DENSITIES [LPD] AND UNIFORMITY

TABLE 11. LPD FOR POOLS IN TEST PROFILE – INCANDESCENT BASE

TEST POOL	AREA (SQ. FT.)	INCANDESCENT (W)	LPD (W/SQ. FT.)	CODE (W)	PASS/FAIL
Hyatt Westlake Village	1,617	1,000	0.62	0.50	Pass
Marriott Desert Springs Spa Pool	2,232.	1,800	.81	0.50	Pass
Marriott Desert Springs Lap Pool	2,508.	900	0.36	0.50	Fail
Marriott Villas - Cassia	948	800	0.85	0.50	Pass
Marriott Villas - Mesquite	1,049	800	0.76	0.50	Pass

TABLE 12. LPD FOR JACUZZI SPAS IN TEST PROFILE – INCANDESCENT BASE

TEST POOL	AREA (SQ. FT.)	INCANDESCENT (W)	LPD (W/SQ. FT.)	CODE (W)	PASS/FAIL
Hyatt Westlake Village	148	500	3.38	0.50	Pass
Marriott Desert Springs Spa	53	300	5.66	0.50	Pass
Marriott Villas - Cassia	154	400	2.60	0.50	Pass

TABLE 13. LPD FOR POOLS IN TEST PROFILE – LED LIGHTING OPTIONS

TEST POOL	AREA (SQ. FT.)	LED (W)	LPD (W/SQ. FT.)	CODE (W)	PASS/FAIL
Hyatt Westlake Village Luminaire E	1,617	144	0.09	0.50	Fail
Hyatt Westlake Village Luminaire B	1,617	94	0.06	0.50	Fail
Marriott Desert Springs Spa Luminaire C	2,232	306	0.14	0.50	Fail
Marriott Desert Springs Lap Pool Luminaire B	2,508	141	0.06	0.50	Fail
Marriott Villas – Cassia – Luminaire D	948	104	0.11	0.50	Fail
Marriott Villas – Mesquite – Luminaire A	1,049	84	0.08	0.50	Fail

TABLE 14. LPD FOR JACUZZI SPAS IN TEST PROFILE – LED LIGHTING OPTIONS

TEST JACUZZI/SPA	AREA (SQ. FT.)	LED (W)	LPD (W/SQ. FT.)	CODE (W)	PASS/FAIL
Hyatt Westlake Village Luminaire E	148	72	0.50	0.50	Pass

TEST JACUZZI/SPA	AREA (SQ. FT.)	LED (W)	LPD (W/SQ. FT.)	CODE (W)	PASS/FAIL
Hyatt Westlake Village Luminaire B	148.	47	0.32	0.32	Fail
Marriott Desert Springs Spa Luminaire C	53	51	0.96	0.50	Pass
Marriott Villas - Cassia Luminaire D	154	51	0.33	0.50	Fail

Discussion of Lighting Power Density (LPD)

LPD for the pools tested with base (incandescent) lighting met minimum requirements for code on all but one of the pools. The LPD range for base lighting tested was 0.48W - 1.08W per square foot. The required (by code) minimum is 0.5W per square foot. The Marriott Desert Springs lap pool at 0.48W was just shy of the 0.5W/sq.ft current code requires. It should be noted, however, that the resort is over 20 yeas old and most likely the current LPD code requirements for pool lighting did not apply when this pool was originally permitted.

All of the Jacuzzi/spa LPD's were well above the 0.5W/sq.ft required by code. LPD's for the spas with base incandescent lighting ranged from 2.60W to 7.55W per square foot.

When using the LED pool lighting alternative light sources the LPD's for the pools tested ranged from a low of 0.06W to a high of 0.14W per square foot. Using the 0.5W per square foot criteria none of the pools would pass code. Two of the Jacuzzi/spas, however, with LPD's of 0.50W and 0.96W per square foot could pass code while the other two with LPD's less than the 0.50W minimum would not pass current code.

There is a provision, however, under the code to demonstrate equivalent light output to the 0.5W/sq.ft illumination based on incandescent lighting. The typical means of demonstrating the equivalency is to demonstrate the lumen efficacy versus the incandescent base of the alternate light source. Applying this provision compares the source lumens of the LED to the incandescent base lumens. The provision as applied to the test pools is as follows:

TABLE 15. LPD ADJUSTMENT LUMEN COMPARISONS – POOLS IN TEST PROFILE

TEST POOL	AREA (SQ. FT.)	INCANDESCENT (LUMENS)	LED (LUMENS)	CODE (LUMENS) *1	PASS/FAIL
Hyatt Westlake Village Luminaire E	1,617	9,150	6,080	7,396	Fail
Hyatt Westlake Village Luminaire B	1,617	9,150	4,000	7,396	Fail
Marriott Desert Springs Spa Luminaire C	2,232.	16,600	14,300	10,318	Pass
Marriott Desert Springs Lap Pool Luminaire B	2,508	8,300	5,772	10,037	Fail
Marriott Villas - Cassia	948	6,400	5,400	3,794	Pass
Marriott Villas - Mesquite	1,049	6,400	1,500	4,197	Fail

*1 Based on proportion of incandescent lumens provided with 0.5W per square foot of incandescent lighting

Applying this same provision to the Jacuzzi/spas in the test produces these results:

TABLE 16. LPD ADJUSTMENT LUMEN COMPARISONS – JACUZZI SPAS IN TEST PROFILE

TEST JACUZZI/SPA	AREA (SQ. FT.)	INCANDESCENT (LUMENS)	LED (LUMENS)	CODE (LUMENS) *1	PASS/FAIL
Hyatt Westlake Village Luminaire E	148	4,574	3,040	677	Pass
Hyatt Westlake Village Luminaire B	148	4,574	1,122	677	Pass
Marriott Desert Springs Spa Luminaire C	53	2,773	2,353	245	Pass
Marriott Villas - Cassia Luminaire D	154	3,201	2,733	1052	Pass

*1 Based on proportion of incandescent lumens provided with 0.5W per square foot of incandescent lighting

While applying the lighting equivalency using lumen comparisons will in some instances allow the lower than 0.5W/sq.ft of LED pool lighting installations to meet pool lighting code compliance, the standard lumen comparative method does not maximize the potential that LED pool lighting has to achieve meaningful lumens throughout the pool with significantly lower LPD's versus conventional incandescent lighting.

Maximizing the full benefit of LED pool lighting requires a provision in the code allowing for a multiplier when LED lighting is used. This multiplier will account for the LED lighting to deliver and distribute more usable lumens within the pool. Discussion concerning the need for this adjustment factor and guidelines for developing the factor are in the Analysis of Anomalies as well as the Conclusions and Recommendations sections of this report.

TABLE 17. LIGHTING UNIFORMITY MIN TO MAX COMPARISONS FOR POOLS IN TEST PROFILE *2

Test Pool	VERTICAL UNIFORMITY		HORIZONTAL UNIFORMITY		Notes & Remarks
	Incandescent Min: Max	LED Option Min: Max	Incandescent Min: Max	LED Option Min: Max	
Hyatt Westlake Village Luminaire E	14:1	10:1	9:1	6:1	Major Improvement
Hyatt Westlake Village Luminaire B	14:1	9:1	9:1	6:1	Major Improvement
Marriott Desert Springs Spa Pool	5:1	3:1	3:1	2:1	Major Improvement
Marriott Desert Springs Lap Pool	11:1	10:1	15:1	17:1	About the Same
Marriott Villas –- Cassia	5:1	4:1	1:1	1:1	Slight Improvement
Marriott Villas – Mesquite	7:1	7:1	4:1	3:1	About the Same

*2 Uniformity rounded off to the closest whole number for table, exact ratio may vary by a maximum of 0.5 +-

TABLE 18. LIGHTING UNIFORMITY AVG TO MIN COMPARISONS FOR POOLS IN TEST PROFILE [*2]

Test Pool	VERTICAL UNIFORMITY		HORIZONTAL UNIFORMITY		Notes & Remarks
	Incandescent Avg: Min	LED Option Avg: Min	Incandescent Avg: Min	LED Option Avg: Min	
Hyatt Westlake Village Luminaire E	2:1	2:1	3:1	3:1	Same uniformity
Hyatt Westlake Village Luminaire B	2:1	4:1	3:1	3:1	Some improvement
Marriott Desert Springs Spa	5:1	3:1	3:1	2:1	Major Improvement
Marriott Desert Springs Lap Pool	3:1	2:1	2:1	2:1	About the Same
Marriott Villas –- Cassia	3:1	3:1	1:1	1:1	Same uniformity
Marriott Villas – Mesquite	2:1	2:1	2:1	2:1	Same uniformity

*2 Uniformity rounded off to the closest whole number for table, exact ratio may vary by a maximum of 0.5 +-

TABLE 19. LIGHTING UNIFORMITY MIN TO MAX COMPARISONS FOR JACUZZI SPAS IN TEST PROFILE [*2]

Test Jacuzzi/Spa	VERTICAL UNIFORMITY		HORIZONTAL UNIFORMITY		Notes & Remarks
	Incandescent Min: Max	LED Option Min: Max	Incandescent Min: Max	LED Option Min: Max	
Hyatt Westlake Village Luminaire E	4:1	2:1	8:1	4:1	Major Improvement
Hyatt Westlake Village Luminaire B	4:1	3:1	8:1	4:1	Major Improvement
Marriott Desert Springs Spa Jacuzzi	12:1	2:1	31:1	25:1	Inconclusive Errors in Data
Marriott Villas – Cassia Jacuzzi	4:1	3:1	5:1	3:1	Some Improvement

*2 Uniformity rounded off to the closest whole number for table, exact ratio may vary by a maximum of 0.5 +-

TABLE 20. LIGHTING UNIFORMITY AVG TO MIN COMPARISONS FOR JACUZZI SPAS IN TEST PROFILE [*2]

Test Jacuzzi/Spa	VERTICAL UNIFORMITY		HORIZONTAL UNIFORMITY		Notes & Remarks
	Incandescent Avg: Min	LED Option Avg: Min	Incandescent Avg: Min	LED Option Avg: Min	
Hyatt Westlake Village Luminaire E	2:1	2:1	4:1	3:1	About the Same
Hyatt Westlake Village Luminaire B	2:1	2:1	4:1	3:1	About the Same
Marriott Desert Springs Spa Jacuzzi	3:1	1:1	12:1	7:1	Major Improvement
Marriott Villas – Cassia Jacuzzi	3:1	2:1	2:1	2:1	About the Same

*2 Uniformity rounded off to the closest whole number for table, exact ratio may vary by a maximum of 0.5 +-

DISCUSSION ON LIGHTING UNIFORMITY

Lighting uniformity is often an attribute found with LED lighting applications versus conventional point source base lighting such as high pressure sodium (HPS), metal halide and incandescent. The LED pool lighting alternatives, for the most part, exhibited this attribute. Dedicated LED lighting systems, such as the LED Luminaire C, D, and E systems tested appear to offer the best uniformity. While the screw-in retrofit LED lamps have potential for improved uniformity as seen with LED Luminaire B, uniformity results are less constant and in some cases poorer than that of incandescent (base) pool lighting as seen with LED Luminaire A.

Uniformity of the LED Luminaire C, D, and E systems measured in the test pools was significantly better than that of the base incandescent lighting uniformities. The LED Luminaire C, D, and E's Min/Max vertical uniformities ranged from 3:1 to 10:1 versus the incandescent counterparts uniformities of 5:1 to 14:1. This significant improvement in uniformity contributes to the design of the whole-fixture system that offers optics and distribution optics built into the system. These optic options allow the pool lights to be field customized and adjusted to specific pool needs. Lighting distributions of narrow and wide are offered as well as the ability to fine-tune aiming direction of the lumen package. There was less variation measured between the incandescent and LED horizontal Min/Max measurements. However, note that because minimal horizontal measurements were recorded, the accuracy of horizontal Min/Max comparisons is subject to significant error. Therefore, the numbers posted are for comparative reference only not for validation of uniformity differences. Similar uniformity improvements were also measured in the spas with the LED Luminaire C, D, and E's option versus the base incandescent. However, unlike the pools, they were not visually apparent.

Screw-in retrofit LED lamps such as the LED Luminaire A and B lamps tested tend to mimic their incandescent counterparts and are usually offered as "one size" fits all. While some of these lamps offer beam distribution that results in improved uniformity when replacing base (incandescent) lighting improved uniformity is not guaranteed. For the most part the LED Luminaire A and B lamps exhibited near equal uniformity (vertical and horizontal) to their incandescent base lighting counterparts. The LED Luminaire B retrofit LED lamps did show some uniformity improvement over the base incandescent lighting at the Hyatt WLV pool. The LED Luminaire B uniformity as recorded by measurement equaled that of the LED Luminaire E.

When using retrofit LED replacement lamps, photometric distribution, as well as lumen output must be scrutinized and compared to the base incandescent lumens and photometric distribution.

This scrutiny assures that the LED retrofit replacements will provide expected light output as well as distribution that assure adequate illumination and acceptable uniformity.

ANALYSIS OF ANOMALIES AND UNIQUE CONDITIONS

ANOMALIES AND CONDITIONS DISCUSSION TOPICS

Several anomalies were encountered during the process of conducting the LED pool lighting study. Some anomalies in recorded light level readings were contributed to the base lighting (incandescent) not having been re-lamped with new lamps prior to the testing. Other anomalies with respect to light level measurements were the result of LED lighting alternates being jury-rigged as opposed to a full install of the LED equipment. Finally, measurement of higher illumination levels, from less lumen, exhibited with some of the LED alternate pool lighting is contributed to the effect of water acting similar to a blue filter. With incandescent lighting most of the available lumens are in the warm (red/yellow) spectrum while the LED used in the testing has more of its lumens in the blue (cooler) spectrum. The cooler lumens travel further in water than the warm lumens because of the "blue filter" effect of the water.

In addition, as stated previously in this report, several conditions with respect to the use of LED pool lighting were encountered. The effect of water to act like a blue filter allowing for better performance of LED lighting within pools versus the incandescent base. Significant performance improvements of the dedicated LED system (LED Luminaire C, D, E) versus LED retrofit lamps (LED Luminaire A and B). Finally, current code compliance criteria, mandating 0.5W per square foot of incandescent illumination or equivalent output. The current provision does not account for effectiveness of LED lighting performance in water.

EFFECTS OF WATER ON POOL LIGHTING

The effect of the water on light waves is similar to that experienced with filters (theatrical and photographic context) to drastically reduce (filter out) portions of the light spectrum that produce visible light in turn measured as illumination.

The filter effect from a large mass of water is to cut out warmer spectrum (red/yellow) initially and eventually the cooler (green/blue) range of visible light. This can be visually experienced as we descend into the ocean or a deep lake. Just below the surface, the visual appearance is similar to that view on land. As we descend in depth the overall visual environment turns green, then blue and finally dark, as is the case in extreme ocean depths. The waters effect is to reduce illumination, cutting out the red spectrum first and the blue last (like a blue filter). This caused the somewhat monochromatic effect of overall green and then blue rendition of the visual environment within the oceans depth.

While not as dramatic as the effects experienced in the ocean or other bodies of water with large expanses, this same "blue filter" effect can occur in swimming pools and Jacuzzi/spas. The influence of the "blue filter" effect on pool lighting is proportional to the size of the pool. Therefore, the effect has a greater influence on

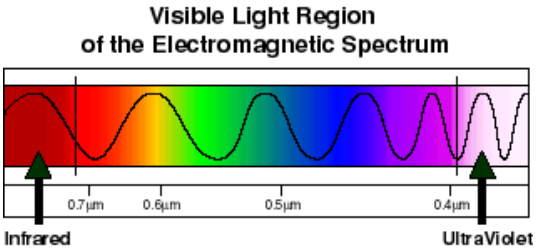
light within larger pools where volume of water is greater and light must travel further distances from the source. This "blue filter" effect however has little to no effect on most Jacuzzi/spas since their water volume is small (versus a pool) and light ravels relatively short distances within the spas.

Measured light levels of LED pool lighting versus equivalent incandescent pool lighting at the pools tested in this study indicates that the "blue filter" effect is sufficient within the larger pools tested to influence the total lumens reaching across a pool surface. This effect is probably most prevalent at the Hyatt Westlake Village pool and Marriott spa pool with the LED Luminaire D and E LED systems. In both of these instances measurements of illumination with the LED systems were significantly higher (documenting that more lumens were reaching the measurement points) than those measured with the incandescent base lighting. To support the effects of this phenomenon the higher levels measured were produced with total available lumens from the light source (LED) and with improved uniformity distribution, which suggests less directional lumens.

ADJUSTMENTS FOR LED LIGHTING WHEN LPD MINIMUMS (CODE DICTATED) ARE NOT MET

Current code defines lighting compliance for pool lighting as providing 0.5W per square foot per surface area of the pool of incandescent lighting. Further provision allows for equivalent lighting provided by alternate light sources as long as the equivalent lighting provides equal illumination to that of the 0.5W/sq.ft of incandescent lighting.

Historically the metric for calculating equivalent lighting is providing the equal quantity of lumens to that of the incandescent base light source. This metric is adequate when the alternate source has a similar spectral distribution to that of the incandescent base. However, the spectral distribution of LED lighting used for pool applications is significantly different from the incandescent source. While incandescent has a high red content and little blue, LED's used in pool lights is high in blue and has proportionately much less red. Refer to images 1 and 2 for spectral distribution of incandescent pool lamps versus LED pool lamps as well as the spectral distribution of visible light. Therefore, a new metric is needed to calculate the equivalent illumination from LED pool lighting versus the incandescent reference base. Use of traditional metrics will result in use of more lighting power than required from the LED source and may also result in an over lighted pool.



Color	Wavelength (nm)
Red	625 - 740
Orange	590 - 625
Yellow	565 - 590
Green	520 - 565
Cyan	500 - 520
Blue	435 - 500
Violet	380 - 435

FIGURE 13. VISIBLE LIGHT REGION OF THE ELECTROMAGNETIC SPECTRUM

PARAMETERS FOR LED POOL LIGHTING METRIC

The metric should allow for the LED's higher content of lumen output in the cooler/blue spectral range as this range is less effected by the "blue filter" effect than is incandescent with its high concentration of lumens in the warmer/red spectral range.

A sliding multiplier that increases as volume and size of the pool increases, provides a reliable metric for "How Much" LED pool lighting will provide equivalent illumination to that of the
0.5W incandescent (per square foot of pool area) as defined by current code compliance mandates.

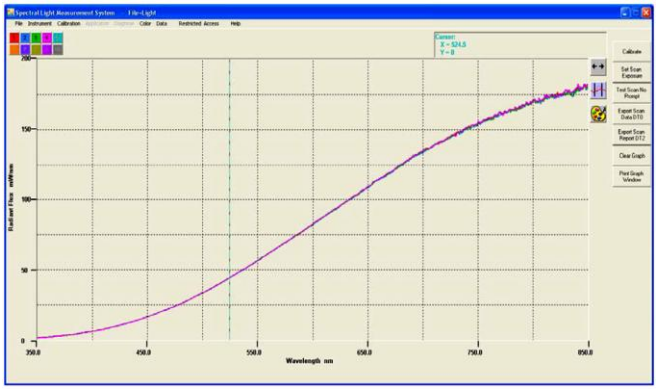


FIGURE 14. 500W INCANDESCENT SPECTRUM

Most of the visual spectral flux of the incandescent is in the 550nm to 740nm (warm/red range).

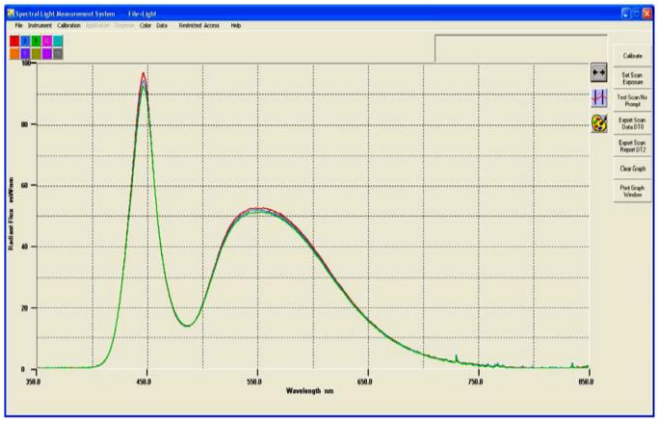


FIGURE 15, IMAGE 2 – 70W LED LUMINAIRE E LED SPECTRUM

Most of the visual spectral flux of the LED is in the 380nm to 565nm (cool/blue range).

PERFORMANCE OF DEDICATED LED SYSTEMS VERSUS RETROFIT LAMPS

Well-designed LED retrofit lamps have potential to provide equivalent illumination at significantly lower LPDs. However, the retrofit lamps do not always provide the performance needed. Current retrofit LED lamp offerings tend to fall into the "one size fits all" profile that may limit their effectiveness in some applications.

Dedicated LED pool lighting systems, such as the LED Luminaire C, D, and E, tend to offer a wider range of performance options and therefore greater potential for maximizing the effectiveness of LED pool lighting. In the analysis of LED pool lighting, the performance of all of the test pools at Hyatt Westlake Village, Marriott Resort Spa and Marriott Villas Cassia, exhibited best performance. In these pools, using the LED Luminaire C, D, and E system versus retrofit lamps, both light levels and uniformity measured were improved versus the base (incandescent) pool lighting. There are some uniformity improvements with screw-in LED Luminaire B but does not match the light level. Refer to images 3 through 4 for visual comparisons of performance as well as comparative data.

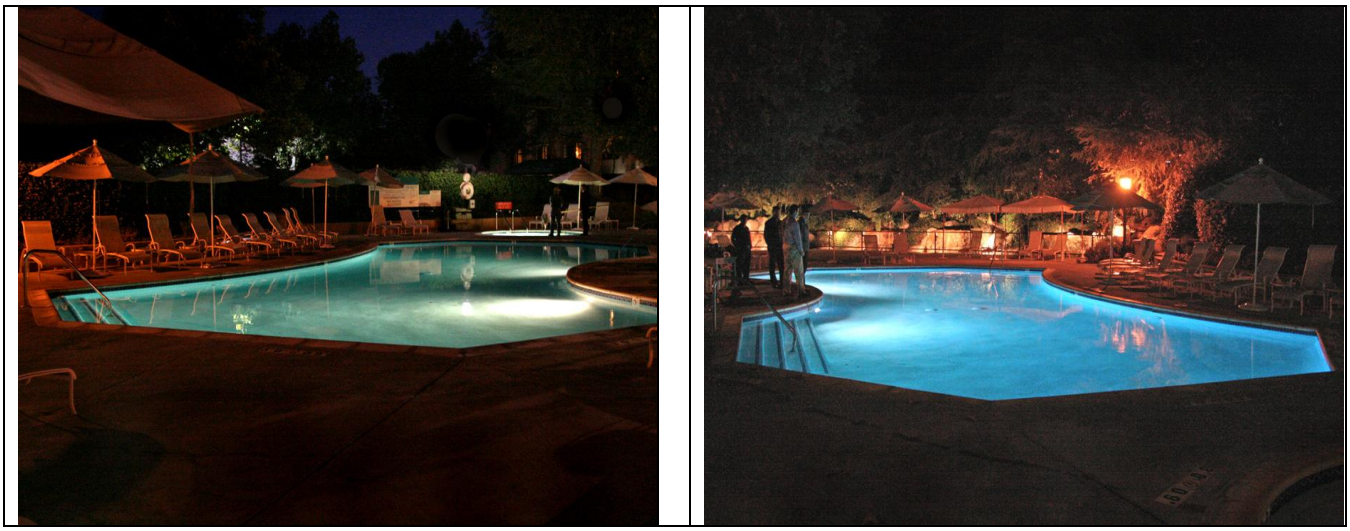


FIGURE 16. HYATT POOL INCANDESCENT (LEFT), AND LED LUMINAIRE (RIGHT)

TABLE 21. STATISTICAL COMPARISONS – INCANDESCENT VERSUS LED FOR HYATT WESTLAKE VILLAGE POOL

Measured Performance	Incand. Lighting	LED Luminaire E Lighting	Improved	Comments/Remarks
Avg Vertical fc	1.66 fc	3.20 fc	93%	Virtually double light output
Avg Horizontal fc	0.74 fc	1.31 fc	78%	Near double light output
Uniformity Min/Max Vertical	4:1	2:1	100%	Double the uniformity
Uniformity Min/Max Horizontal	8:1	4:1	100%	Double the uniformity
Manufacturers Rated Wattage	500W	70W	86% less W	Total 860 less watts *(2 lamps)*
Measured Lumens *(Sphere Test)*	4600 Lm	3100 Lm	-1500 Lm	33% less lumens per lamp
Lighting Power Density *(1,617 Sq. Ft. Pool Area)*	0.62W/Sq. Ft.	0.09W/Sq. Ft.	85%	LPD reduced by 0.53W with less lumens used and almost double the illumination

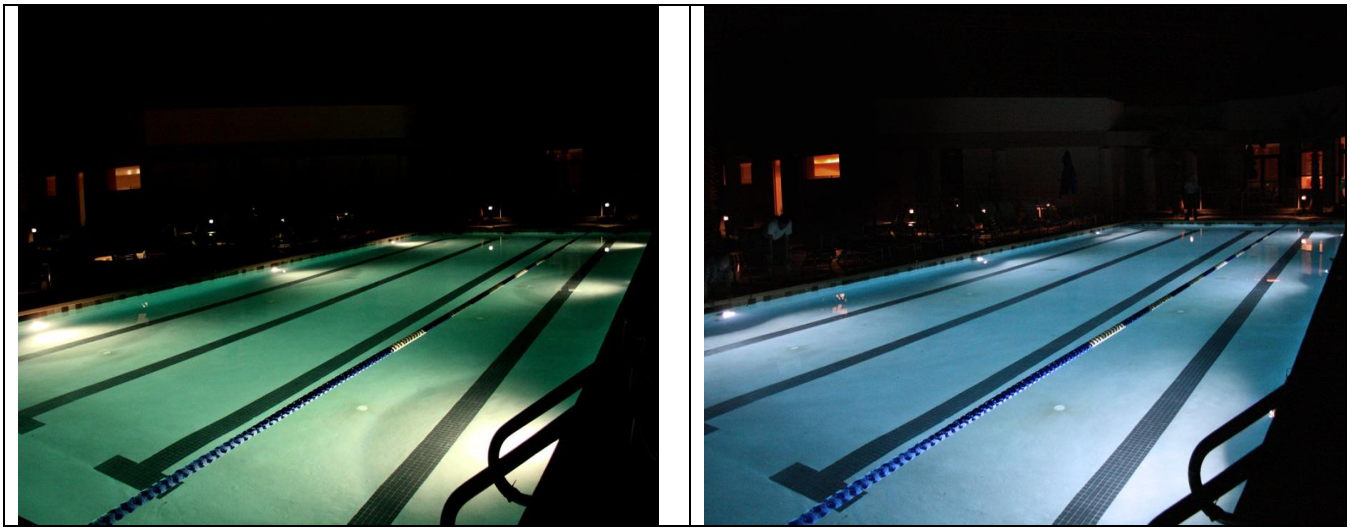


FIGURE 17. MARRIOTT SPA POOL I*NCANDESCENT (LEFT) AND LED LUMINAIRE (RIGHT)

TABLE 22. STATISTICAL COMPARISONS – INCANDESCENT VERSUS LED FOR MARRIOTT SPA POOL

MEASURED PERFORMANCE	INCAND. LIGHTING	LED LUMINAIRE C LIGHTING	IMPROVED	COMMENTS/REMARKS
Avg Vertical fc	3.13 fc	3.61 fc	16%	Slightly better than equal output
Avg Horizontal fc	3.11 fc	3.70 fc	19%	Slightly better than equal output
Uniformity Min/Max Vertical	5:1	3:1	40%	Better uniformity
Uniformity Min/Max Horizontal	3:1	2:1	70%	Much better uniformity
Manufactures Rated Wattage	300W	45W	85% less W	Total 1530 less watts *(6 lamps)*
Measured Lumens *(Sphere Test)*	2100 Lm	2300 Lm	200 Lm	10% more lumens per lamp
Lighting Power Density *(2232 Sq. Ft. Pool Area)*	0.81W Sq. Ft.	0.12W Sq. Ft.	85%	LPD reduced by 0.69W, 10% more lumens and 16% to 19% higher illumination

FIGURE 18. VILLAS CASSIAS POOL INCANDESCENT (LEFT) AND LED LUMINAIRE (RIGHT)

TABLE 23. STATISTICAL COMPARISONS – INCANDESCENT VERSUS LED FOR VILLAS CASSIA POOL

MEASURED PERFORMANCE	INCAND. LIGHTING	LED LUMINAIRE D LIGHTING	IMPROVED	COMMENTS/REMARKS
Avg Vertical fc	2.94 fc	3.63 fc	23%	Slightly better than equal output
Avg Horizontal fc	2.30 fc	2.67 fc	16%	Slightly better than equal output
Uniformity Min/Max Vertical	5:1	4:1	20%	Better uniformity
Uniformity Min/Max Horizontal	1:1	1:1	0%	Equal uniformity
Manufacturers Rated Wattage	400W	50W	87% less W	Total 700 less watts *(2 lamps)*
Measured Lumens *(Sphere Test)*	3200 Lm	2700 Lm	-500 Lm	15% less lumens per lamp
Lighting Power Density *(948 Sq. Ft. Pool Area)*	0.84W Sq. Ft.	0.11W Sq. Ft.	87%	LPD reduced by 0.73W 15% less lumens and 16% to 23% higher illumination

The superior performance of the dedicated LED system is attributed to its design characteristics. As a system design versus a retrofit lamp, thermal management and optics design are maximized. This "fine tuning" of components within the system results in improved performance over retrofit lamps. It also allows for higher lumen packages and variable optics not found in typical retrofit LED lamps. The LED Luminaire C, D, and E systems offered lumen packages from 2,300 – 3,100 lumens and the ability to produce narrow or wide distribution within the same luminaire via "on site" tuning of optics.

OTHER OBSERVED ANOMALIES AND INCONSTANCIES

Several additional anomalies and inconstancies that occurred and/or observed during the pool lighting testing include:

- Existing incandescent base lamps at the Marriott Hotel lap pool were not re-lamped with new lamps prior to baseline testing. Lack of re-lamping skewed baseline measurements.
- LED Luminaire C, D, and E were jury-rigged for testing since they had not received UL approval for installation at the time testing occurred. Jury-rigging affected some of the readings, which in turn skewed the performance.
- LED Luminaire B screw-in LED retrofit lamps added to the Hyatt Westlake Village testing were also jury-rigged. Jury-rigging may have skewed the performance at this pool.
- Marriott Desert Springs Hotel lap pool LPD was below the 0.5W/sq.ft minimum as required by current code. Recorded light levels were lower with both incandescent and the LED alternate compared to the other pools in the test profile.
- LED Luminaire A retrofit lamps at the Marriott Villas Mesquite pool exhibited unusually poor performance and optic anomalies. Performance was not on a par with the other LED products tested.

Analysis and discussion of these anomalies and inconstancies are covered below.

INCANDESCENT BASE LAMPS, MARRIOTT HOTEL LAP POOL, NOT RE-LAMPED

Because some of the incandescent lamps were not re-lamped, light levels measured for the base lighting are most likely less than peak (new lamp) output. In addition, with lumen variation between lamps caused by lamps that were not new, uniformity was affected as well. Without a re-measure with all newly re-lamped base lighting there is no way to quantify the variation in light output and uniformity. A "ball park" estimate, based on familiarity with incandescent lamp performance, is 10% to 15% less light and the equivalent less uniformity than that which might be measured if the pool base lighting had been re-lamped with all new lamps.

LED Luminaires C, D, and E were jury-rigged for testing

Jury-rigging resulted in the LED Luminaire C, D, and E lamps not installed flush in the pool, as they would be under a normal installation. The lamp face projected about 12-inch's into the pool. This projection had little if any effect on overall (average) light-output measured but may have affected several of the point measurements that in turn would affect uniformity. However, uniformity measured for the LED Luminaire C, D, and E (jury-rigged) was superior to the base lighting. Therefore, this anomaly is not considered a significant detractor to the overall evaluation and resulting performance of the lighting system.

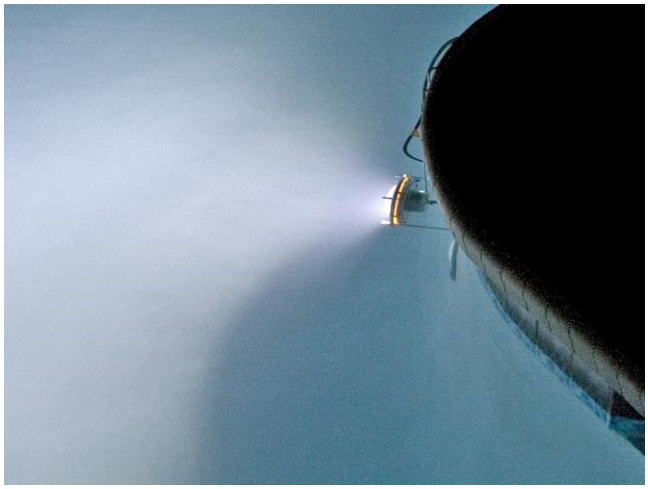


FIGURE 19. IMAGE 9 – LED LUMINAIRE D JURY-RIGGED AT CASSIA POOL

LED LUMINAIRE B SCREW-IN LED RETROFIT LAMPS AT HYATT WESTLAKE VILLAGE TESTING WERE ALSO JURY-RIGGED

As with the LED Luminaire C, D, and E, jury-rigging of LED Luminaire B lamps also resulted in the lamps not flush, as they would be under a normal installation. The lamp face projected about 18-inch's into the pool. This projection on the lamps had little affect on overall (average) light-output but may have affected several of the point measurements that in turn would negatively affect uniformity. Uniformity measured for the LED Luminaire B (jury-rigged) was 40% better than the base incandescent lighting. Therefore, this anomaly with the LED Luminaire B lamps at the Hyatt pool are not considered a detractor to the overall evaluation and resulting performance of the LED Luminaire B lamps in this test.

FIGURE 20. LED LUMINAIRE B JURY-RIGGED AT HYATT POOL

MARRIOTT DESERT SPRINGS HOTEL LAP POOL LPD BELOW THE 0.5W MINIMUM REQUIRED BY CODE

While the LPD at this pool is below the current 0.5W square foot of pool area, this anomaly has no effect on the LED versus incandescent testing that occurred. The objectives for the LED pool lighting project are to evaluate performance and efficacy of LED lighting versus baseline incandescent lighting in swimming pools and Jacuzzi spas. This pool met the objectives even though its LPD code requirement fell short of current mandates.

LED LUMINAIRE A RETROFIT LAMPS AT MARRIOTT VILLAS MESQUITE POOL SHOWED POOR OPTICS AND PERFORMANCE

The LED Luminaire A retrofit lamps were underpowered for the task required. With a lumen package of 739 lm versus 3,200 lm for the incandescent base lighting the LED Luminaire A lighting simply could not approach the illumination levels of the incandescent. Furthermore, the lamp optics exhibited artifacts within the beam that were visually noticeable, and may have contributed to poor performance of these lamps.

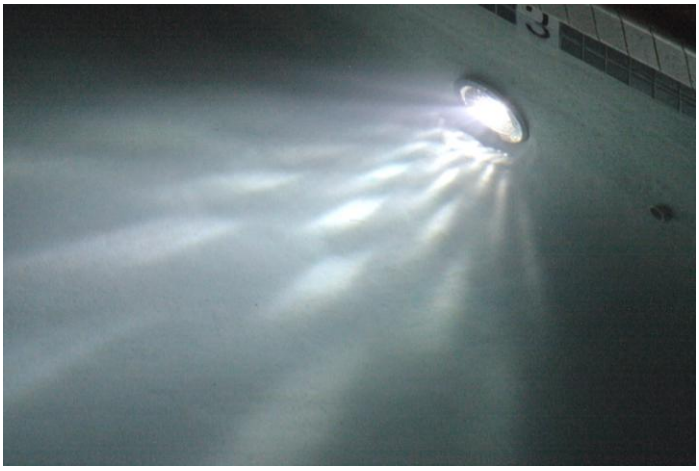


FIGURE 21. LED LUMINAIRE A LAMP INSTALLED AT MESQUITE POOL

COST EVALUATION

Cost can vary significantly in pool lighting depending on whether it is a simple lamp replacement or a whole fixture replacement. Table 24 shows the cost of replacing an existing incandescent pool lamp and the whole fixture. The costs used in this report are from the manufacturers or from the paid invoice of the actual cost pertaining to this project.

TABLE 24. TOTAL RETROFIT COST OF EXISTING INCANDESCENT LAMP

	QTY	TOTAL COST OF LAMP	TOTAL COST OF GASKET	TOTAL COST OF FIXTURE	TOTAL LABOR	TOTAL RETROFIT COST
Replacing One Incandescent Lamp	1	$ 8.26	$ 16.11	-	$ 65.00	**$ 89.37**
Replacing One Incandescent Fixture	1	-	-	$213.51	$130.00	**$ 343.51**

The difference between the retrofit and new fixture replacement of the incumbent incandescent technology is the fixture and labor cost. The cost of the fixture is $213.51 and the labor takes an extra hour to install.

Table 25 shows the cost of each test site and the LEDs that were installed. Luminaires C, D, and E are whole fixture replacements that take an extra hour to install per fixture and do not require a new gasket.

TABLE 25. TOTAL LED MEASURE INSTALL COST PER LAMP

	Measure Description	Qty	Measure Cost	Gasket Cost	Labor	Total Measure Install Cost per Lamp
Hyatt Pool	Luminaire B	2	$ 592.00	$16.11	$65.00	**$ 673.11**
Hyatt Pool	Luminaire E	2	$ 553.26	$ -	$65.00	**$ 754.99**
Hyatt Jacuzzi	Luminaire B	1	$ 592.00	$16.11	$65.00	**$ 673.11**
Hyatt Jacuzzi	Luminaire E	1	$ 553.26	$ -	$65.00	**$ 754.99**
Marriott Villas Mesquite Pool	Luminaire A	2	$ 318.99	$16.11	$65.00	**$ 400.10**
Marriott Villas Cassia Pool	Luminaire D	2	$ 515.26	$ -	$65.00	**$ 754.99**
Marriott Villas Cassia Jacuzzi	Luminaire D	1	$ 515.26	$ -	$65.00	**$ 754.99**
Marriott Resort Spa Pool	Luminaire C	6	$ 475.26	$ -	$65.00	**$ 754.99**
Marriott Resort Lap Pool	Luminaire B	3	$ 592.00	$16.11	$65.00	**$ 673.11**

	Measure Description	Qty	Measure Cost	Gasket Cost	Labor	**Total Measure Install Cost per Lamp**
Marriott Resort Spa Jacuzzi	Luminaire C	1	$ 475.26	$ -	$65.00	**$ 754.99**

The costs shown in Table 25 are only listed per lamp. The total cost can be multiplied by the quantity shown for the actual cost of the site.

Based on the cost results shown in Table 26, the total cost of LED systems can cost more than seven times that of the incandescent retrofits. The payback calculations are in the Energy Savings section of this report.

TABLE 26. INCREMENTAL COST OF LED PER LAMP

	Measure Description	Total Incandescent Retrofit Cost per Lamp	Total LED Install Cost per Lamp	**Incremental Cost of LED per Lamp**
Hyatt Pool	Luminaire B	$ 89.37	$ 673.11	**$ 583.74**
Hyatt Pool	Luminaire E	$ 89.37	$ 754.99	**$ 665.62**
Hyatt Jacuzzi	Luminaire B	$ 89.37	$ 673.11	**$ 583.74**
Hyatt Jacuzzi	Luminaire E	$ 89.37	$ 754.99	**$ 665.62**
Marriott Villas Mesquite Pool	Luminaire A	$ 89.37	$ 400.10	**$ 310.73**
Marriott Villas Cassia Pool	Luminaire D	$ 89.37	$ 754.99	**$ 665.62**
Marriott Villas Cassia Jacuzzi	Luminaire D	$ 89.37	$ 754.99	**$ 665.62**
Marriott Resort Spa Pool	Luminaire C	$ 89.37	$ 754.99	**$ 665.62**
Marriott Resort Lap Pool	Luminaire B	$ 89.37	$ 673.11	**$ 583.74**
Marriott Resort Spa Jacuzzi	Luminaire C	$ 89.37	$ 754.99	**$ 665.62**

ENERGY SAVINGS EVALUATION

The operating hours greatly determine the energy use and savings, which in turn play a role in how fast the LED option will pay back the investment made in it. Table 27 shows the energy (kWh) savings per lamp from replacing incandescent lamps with LEDs at the actual test sites.

TABLE 27. ANNUAL KWH SAVED

	Measure Description	Number of Lamps per Site	Total Base Wattage	Total Measure Wattage	Annual Operating Hours	kW Reduced per Lamp	**kWh Saved per Lamp**
Hyatt Pool	LED Luminaire B	2	944.8	98.8	1460	0.4230	**617.58**
Hyatt Pool	LED Luminaire E	2	944.8	134.8	1460	0.4050	**591.30**
Hyatt Jacuzzi	LED Luminaire B	1	472.4	49.4	1460	0.4230	**617.58**
Hyatt Jacuzzi	LED Luminaire E	1	472.4	67.4	1460	0.4050	**591.30**
Marriott Villas Mesquite Pool	LED Luminaire A	2	812.8	51.6	1460	0.3806	**555.68**
Marriott Villas Cassia Pool	LED Luminaire D	2	812.8	104.8	1460	0.3540	**516.84**
Marriott Villas Cassia Jacuzzi	LED Luminaire D	1	406.4	52.4	1460	0.3540	**516.84**
Marriott Resort Spa Pool	LED Luminaire C	6	1638	252.6	4745	0.2309	**1095.62**
Marriott Resort Lap Pool	LED Luminaire B	3	819	148.2	4745	0.2236	**1060.98**
Marriott Resort Spa Jacuzzi	LED Luminaire C	1	273	42.1	4745	0.2309	**1095.62**

Although the Marriott Resort has a lot lower demand reduction than the other two sites, the result of the longer operating hours reflects on the annual energy savings per lamp. The energy savings will also contribute to the payback.

Table 28 shows the money saved by replacing the incandescent lamps with LEDs. Fifteen cents per kWh is used to calculate the dollars saved in a year per lamp.

TABLE 28. DOLLARS SAVED PER YEAR

	Measure Description	Annual Operating Hours	kWh Saved per Lamp	$/kWh	$ Saved/yr
Hyatt Pool	Luminaire B	1460	617.58	$ 0.15	**$ 92.64**
Hyatt Pool	Luminaire E	1460	591.30	$ 0.15	**$ 88.70**
Hyatt Jacuzzi	Luminaire B	1460	617.58	$ 0.15	**$ 92.64**
Hyatt Jacuzzi	Luminaire E	1460	591.30	$ 0.15	**$ 88.70**
Marriott Villas Mesquite Pool	Luminaire A	1460	555.68	$ 0.15	**$ 83.35**
Marriott Villas Cassia Pool	Luminaire D	1460	516.84	$ 0.15	**$ 77.53**
Marriott Villas Cassia Jacuzzi	Luminaire D	1460	516.84	$ 0.15	**$ 77.53**
Marriott Resort Spa Pool	Luminaire C	4745	1095.62	$ 0.15	**$ 164.34**
Marriott Resort Lap Pool	Luminaire B	4745	1060.98	$ 0.15	**$ 159.15**
Marriott Resort Spa Jacuzzi	Luminaire C	4745	1095.62	$ 0.15	**$ 164.34**

Using the dollars saved per year from Table 28, a simple payback can be calculated as shown in Table 29. The simple payback calculation is based only on the energy savings and the initial investment. The Marriott Resort Spa is the only test site that had longer operating hours - 13. Other sites only ran for four hours a day. Although using LED technology saves up to 94% energy, it can still take up to 7.2 years for the energy savings to pay back for the technology.

TABLE 29. SIMPLE PAYBACK

	Measure Description	Incremental Cost	$ saved per year	**Years to Pay Back**
Hyatt Pool	Luminaire B	$ 291.74	$ 92.64	**3.1**
Hyatt Pool	Luminaire E	$ 593.89	$ 88.70	**6.7**
Hyatt Jacuzzi	Luminaire B	$ 291.74	$ 92.64	**3.1**
Hyatt Jacuzzi	Luminaire E	$ 593.89	$ 88.70	**6.7**
Marriott Villas Mesquite Pool	Luminaire A	$ 310.73	$ 83.35	**3.7**
Marriott Villas Cassia Pool	Luminaire D	$ 555.89	$ 77.53	**7.2**
Marriott Villas Cassia Jacuzzi	Luminaire D	$ 555.89	$ 77.53	**7.2**
Marriott Resort Spa Pool	Luminaire C	$ 515.89	$ 164.34	**3.1**
Marriott Resort Lap Pool	Luminaire B	$ 291.74	$ 159.15	**1.8**
Marriott Resort Spa Jacuzzi	Luminaire C	$ 515.89	$ 164.34	**3.1**

Lifecycle cost (LCC) is calculated for all the test sites for both 4-hour and 12-hour operations using the lifecycle cost calculator.[1] The expected life of the LED system is used as the basis of the years of operation using the costs from Table 24 and Table 25. The LCC for LED and incandescent systems are shown for comparison.

TABLE 30. LIFE-CYCLE COST FOR 4 AND 12 HOUR OPERATING DAYS

	Measure Description	4 Hour Operating Days			12 Hour Operating Days		
		Years of Operation	**Measure LCC ($)**	**Base LCC ($)**	Years of Operation	**Measure LCC ($)**	**Base LCC ($)**
Hyatt Pool	Luminaire B	34	**$556**	**$2533**	11.4	**$681**	**$4274**
Hyatt Pool	Luminaire E	34	**$922**	**$2533**	11.4	**$1093**	**$4274**
Hyatt Jacuzzi	Luminaire B	34	**$556**	**$2533**	11.4	**$681**	**$4274**
Hyatt Jacuzzi	Luminaire E	34	**$922**	**$2533**	11.4	**$1093**	**$4274**
Marriott Villas Mesquite Pool	Luminaire A	13.7	**$455**	**$1420**	4.56	**$473**	**$1859**
Marriott Villas Cassia Pool	Luminaire D	34	**$831**	**$2299**	11.4	**$964**	**$3873**
Marriott Villas Cassia Jacuzzi	Luminaire D	34	**$831**	**$2299**	11.4	**$964**	**$3873**
Marriott Resort Spa	Luminaire C	34	**$755**	**$1826**	11.4	**$861**	**$3063**

	Measure Description	4 Hour Operating Days			12 Hour Operating Days		
		Years of Operation	**Measure LCC ($)**	**Base LCC ($)**	Years of Operation	**Measure LCC ($)**	**Base LCC ($)**
Pool							
Marriott Resort Lap Pool	Luminaire B	34	**$556**	**$1826**	11.4	**$681**	**$3063**
Marriott Resort Spa Jacuzzi	Luminaire C	34	**$755**	**$1826**	11.4	**$861**	**$3063**

Based on the LCC analysis for 4-hour operation per day, it is shown that LED systems cost from $16 to $33 per year to operate while incandescent systems cost from $53 to $103 per year. This is a significant reduction in operation costs given that there are incandescent lamp replacements every 2,000 hours including labor.

CONCLUSIONS

Use of LED lighting sources for pool lighting has tremendous potential in both energy savings and aesthetics. LED lamps and luminaire systems save at least 80% in energy while using cooler 5,000K – 7,000K chromaticity that is well suited to pool and Jacuzzi/spa lighting applications.

Though LED pool lighting has great potential, there are several hurdles to adoption of LED pool and Jacuzzi/spa lighting. Significant hurdles include:

- Current code requirements for pools of 0.5W per square foot of incandescent or equivalent lighting, does not take into account the unique performance properties delivered by cool color LED's. This can result in using higher power density of LED lighting than is needed to provide adequate pool illumination.
- Some pools and spas nighttime operating hours are limited resulting in minimal cost avoidance for using high efficiency LED's versus conventional incandescent light sources.
- Present high initial cost of LED lighting versus incandescent lighting minimizes the potential advantages of LED lighting for customers with short operating hours.
- Potential over lighting, driven by current code-compliance requirements, can further impact the first cost hurdles associated with use of LED lighting for pools.

SIGNIFICANT ENERGY SAVINGS

Typical incandescent pool lighting wattages of 300, 400, and 500 Watts present a great potential in saving energy when using LEDs as an alternative source. Tests show that using LED pool lights can save from 80% up to 94% energy while having equivalent light or better. Depending on the operating hours, the annual kWh savings can range anywhere from 500 to almost 1,100 kWh/yr per lamp.

SUPERIOR LIGHT OUTPUT PERFORMANCE OF LEDS

LED light sources are ideal for pool lighting. LED lamps and luminaire systems using cooler to 7,000K chromaticity LEDs are especially effective as the majority of their available lumens are in the cooler visible light spectrum. This spectrum (bluer light) is less affected by water in the pool, which acts like a blue filter. As a result, lumens that are more available travel further in the pool providing a higher level of illumination than an equivalent incandescent light source. Most of the lumens in conventional incandescent is in the warmer (red – yellow spectrum), which is highly degraded by the blue filter effect of water in the pool.

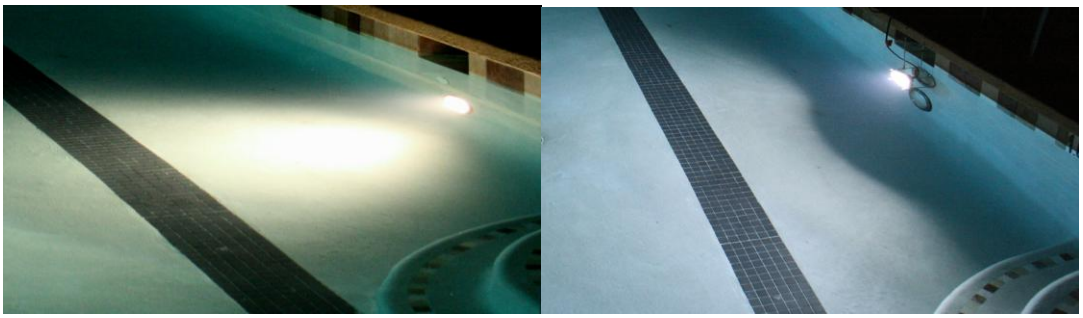


FIGURE 22. INCANDESCENT VERSUS LED

With incandescent pool lighting there is a typical hot spot from the lamp a few feet into the pool as shown in Figure 22. The hot spot is less prevalent with typical LED pool lighting. Rapid fall-off of the lumens in a pool with incandescent lighting results in less even distribution of available lumens into the pool. The rapid fall-off of the lumens in part is the cause of the visual hot spot.

LED lighting with its bluer spectrum results in lumens from the lamp traveling further under water than incandescent lumens, which tends to minimize a visual hot spot and results in higher-measured light levels than incandescent sources. Furthermore, this characteristic of LED pool lights often results in improved uniformity.

FIRST COST HURDLE *(LIMITED OPERATIONS SCENARIOS)* FOR LEDS CAN BE OVERCOME

Since some pool/spa nighttime operating hours are limited to no more than three to five hours daily, current high first cost of LED pool lighting may present a hurdle to adoption of LED pool and Jacuzzi/spa lighting. However, LED lightings' long life and superior performance relative to incandescent lighting could encourage those now operating limited nighttime hours to extend their operating hours. The rationale for extending hours of operation for this group of users is:

- Dusk-to-dawn operation using LED lighting will cost no more than current limited operating hours with incandescent lighting.
- Even with extended hours LED's 50,000+ hours of lamp life will result in little or no lamp maintenance (replacements) within a ten-year period.
- Extended dusk to dawn operation will result in improved safety and increased security at pools, Jacuzzi spas and adjacent areas. Furthermore, these increased safety and security benefits can be obtained while lowering overall operation and maintenance costs

LED POOL LIGHTING DISADVANTAGE WITH RESPECT TO CURRENT LPD CRITERIA

Code requirements with reference to pool and Jacuzzi spa lighting where/when recreational pools are concerned are minimal. In addition, most IESNA lighting recommendations for pools focus on competitive and water sports/activities, not social recreational, hospitality and residential venue pool lighting. The only standard or code compliance reference to pool lighting calls for a minimum of 0.5W per square foot surface pool area (incandescent light source) or equivalent light output.

The 0.5W/sq.ft standard, as currently interpreted, places LEDs at a disadvantage to incandescent and other light sources whose bulk of lumens are within the warmer (2,700K – 3,500K) color spectrum. Higher than needed lumen output and resultant

LED power as well as an over lighted pool can result as a byproduct of attempting to meet the current basis for the minimum 0.5W/sq.ft LPD threshold.

From data gathered during the testing of incandescent versus LED pool lighting using the watts LPD approach (0.5W square foot) criteria, the LED light sources would illuminate the pools to an excessively high level versus a similar incandescent lighting pool. Table 31 outlines the effects of using the watts per square foot criteria on a 3,000 square foot pool with three 500W pool lights. Light levels using the same power density of a LED source could increase by four to five times over that of the light levels in an equivalent incandescent lighted pool.

TABLE 31. USING 0.5W CODE COMPLIANCE REQUIREMENTS

Light Source	Pool Watts (W)	Pool Lumens (Lm)	Initial Average Foot-candles (fc)		Light Level Factor
			Vertical	Horizontal	
Incandescent	1500	14,000	1.5	0.7	1.0X (base level)
LED	1500	65,600	7.0	3.3	4.5X (4-1/2 times base level)

The traditional lumen approach (currently accepted by code authorities), for an equivalent light source results in a scenario where less LED wattage is required and the pools over lighting potential is reduced versus the pure 0.5W minimum LPD requirement. Table 32 depicts this scenario for the same 3,000 square foot pool example. While results are better than in the first scenario, the LED lighting system is still at a disadvantage with respect to its full energy savings potential. Light levels produced by the LED system will also still be much higher than that of the 0.5W incandescent base model.

TABLE 32. USING LUMEN EQUIVALENT METHOD

Light Source	Pool Watts (W)	Pool Lumens (Lm)	Initial Average Foot-candles (fc)		Light Level Factor
			Vertical	Horizontal	
Incandescent	1500	14,000	1.5	0.7	1.0X (base level)
LED	1500	65,600	7.0	3.3	4.5X (4-1/2 times base level)

The ideal approach, for an LED equivalent light source high in blue spectrum (cool white) lumens is to compare lumens and resulting illumination through a blue filter source (The blue filter being an expensive volume of water). With this scenario, LED pool lighting wattage required to illuminate the pool to an incandescent base lighting scheme is minimum. Test demonstrations confirm this hypnosis, as significantly less lumens were required to light the pools to an equal illumination level versus the base incandescent pool lighting. From the testing, the inference is that a 3,000 square foot pool can be illuminated using ½ the lumens of that required when using the incandescent base source. Table 33 depicts the LED lumens needed to produce equal illumination to a base incandesce pool lighting design.

TABLE 33. ADJUSTING FOR BLUE FILTER EFFECT

Light Source	Pool Watts (W)	Pool Lumens (Lm)	Initial Average Foot-candles (fc)		Light Level Factor
			Vertical	Horizontal	
Incandescent	1500	14,000	1.5	0.7	1.0X (base level)
LED	160	7,000	1.5	0.7	1.0X (equal to base level)

For LED based pool lighting to become an effective alternate to incandescent pool lighting and to minimize "over lighting", an adjustment matrix needs to be adopted when the pool lighting is required to meet 0.5W/sq.ft incandescent LPD requirements as condition of code compliance.

Developing an accurate and reliable metric requires extensive additional research and scientific testing. The metric must take into account pool size, volume of water through distances and locations of luminaires. A scientific base for the proportionate "blue filter" effect of large volumes of water must also be defined and applied to the metric. While there are a number of complexities needed to design the matrix accurately, the format for applying and using it must be relatively simple.

Table 34 is an example of what a volume based "blue filter" LED compensation table might look like.

TABLE 34. LUMEN ADJUSTMENT

Size Of Pool	Lumen Adjustment [starting point]	AGI-32 MODEL VERIFICATION
0 to 500 Square Feet	1X *(same as base incandescent lumens*	Using starting point verify lighting requirements through AGI-32 computer modeling of pool design
500 to 1000 Square Feet	2X (*1/2 of the base incandescent lumens*	
1000 to 3000 square feet	3X (*1/3 of the base incandescent lumens*	
Over 3000 Square Feet	4X (*1/4 of the base incandescent lumens*	

RECOMMENDATIONS

Use of LED light sources for pool and Jacuzzi/spa lighting applications should be encouraged. LED lighting has significant advantages for these applications versus the common incandescent lighting often used for such applications. The field tests have shown that significant energy can be saved, especially for sites that operate the pool lights from dusk to dawn. To maximize the advantages of LED light sources, for pools and spas, LED luminaire systems and/or retrofit lamps can employ cooler 5,000K – 7,000K chromaticity LED's. This color LED is especially suited to pool and Jacuzzi/spa lighting applications.

Caution must be exercised when recommending the use of LED pool lighting where/when code compliance issues are involved. Furthermore, some type of adjustment factor that is recognized by code authorities as well as the lighting and engineering communities' needs to be established for LED light source applications used for pool lighting.

SCE's promotion of Commercial LED Pool and/or Jacuzzi and Spa lighting should post the following disclaimers:

- Use of LED pool lighting does not preclude user's responsibility for compliance with all code requirements and lighting performance recommendations where applicable to pool lighting applications.
- SCE's recommendation for use of LED light sources and/or incentive reimbursements with respect for use of LED pool lighting is not meant to serve as a design standard or code-compliance alternative. Design criteria and code compliance are the sole responsibility of the end user not SCE.
- Specific use and application of LED pool lighting is the sole responsibility of the user. SCE is not responsible for and/or carry liability for design application, maintenance and performance of LED pool lighting systems or retrofit lamps used by its customers.

With respect to defining and creating an industry accepted adjustment factor for LED pool lighting applications SCE may want to present a pro-active presence. Areas where SCE can focus include:

- Soliciting input from pool and spa manufacturers as well as LED manufactures with respect to potential adjustment factors for use LED light sources for pool lighting.
- Conducting "fact finding" studies and promote research to identify the components and guidelines needed to create the recommended adjustment factor tables and criteria.
- Facilitating dialog between code authorities, governmental agencies, pool lighting stakeholders and lighting application stakeholders. Objective; draft a consensus document accepted by industry, design and code authorities.

APPENDIX A – TECHNOLOGY TEST CENTERS

LOCATION

All laboratory tests, referenced in this report, were conducted at SCE's Technology Test Centers (TTC) in Irwindale, California. The TTC includes the Thermal Technology Test Center (TTTC) and the Lighting Technology Center (LTTC).

TECHNOLOGY TEST CENTERS

The mission of the TTC is to spread awareness of viable integrated demand-side management solutions to a wide range of SCE customers and energy efficiency (EE) programs. Through impartial laboratory testing and analysis of technologies, the portfolio of EE measure offerings can be expanded with quantified energy savings and alleviation of concerns about performance uncertainties. Testing in a laboratory setting allows for the performance of detailed and replicable tests that are realistic, impartial, and not influenced by unwanted variables while in a controlled environment.

THERMAL TECHNOLOGY TEST CENTER

Controlled environment testing is conducted at SCE's Thermal Technology Test Center (TTTC). This state-of-the-art research and testing facility examines refrigeration, air conditioning, cold storage, and other thermal-based technologies in support of SCE's Energy Efficiency (EE) programs, customers, and industry partners. The lab features walk-in controlled-environment chambers with impressive refrigeration and heating capacity, numerous types of test equipment and tools, and the ability to perform in-house calibration of many related instruments.

LIGHTING TECHNOLOGY TEST CENTER

Integrating sphere testing is conducted at SCE's LTTC. In partnership with the California Lighting Technology Center (CLTC) in Davis, California, LTTC's mission is to foster the application of EE lighting and day-lighting technologies, in cooperation with the lighting industry, lighting professionals, and the design-engineering community. Unique lighting and day-lighting test equipment, EE lighting displays, and flexible black-out test areas enable the evaluation and demonstration of various lighting technologies and applications.

APPENDIX B – EQUIPMENT

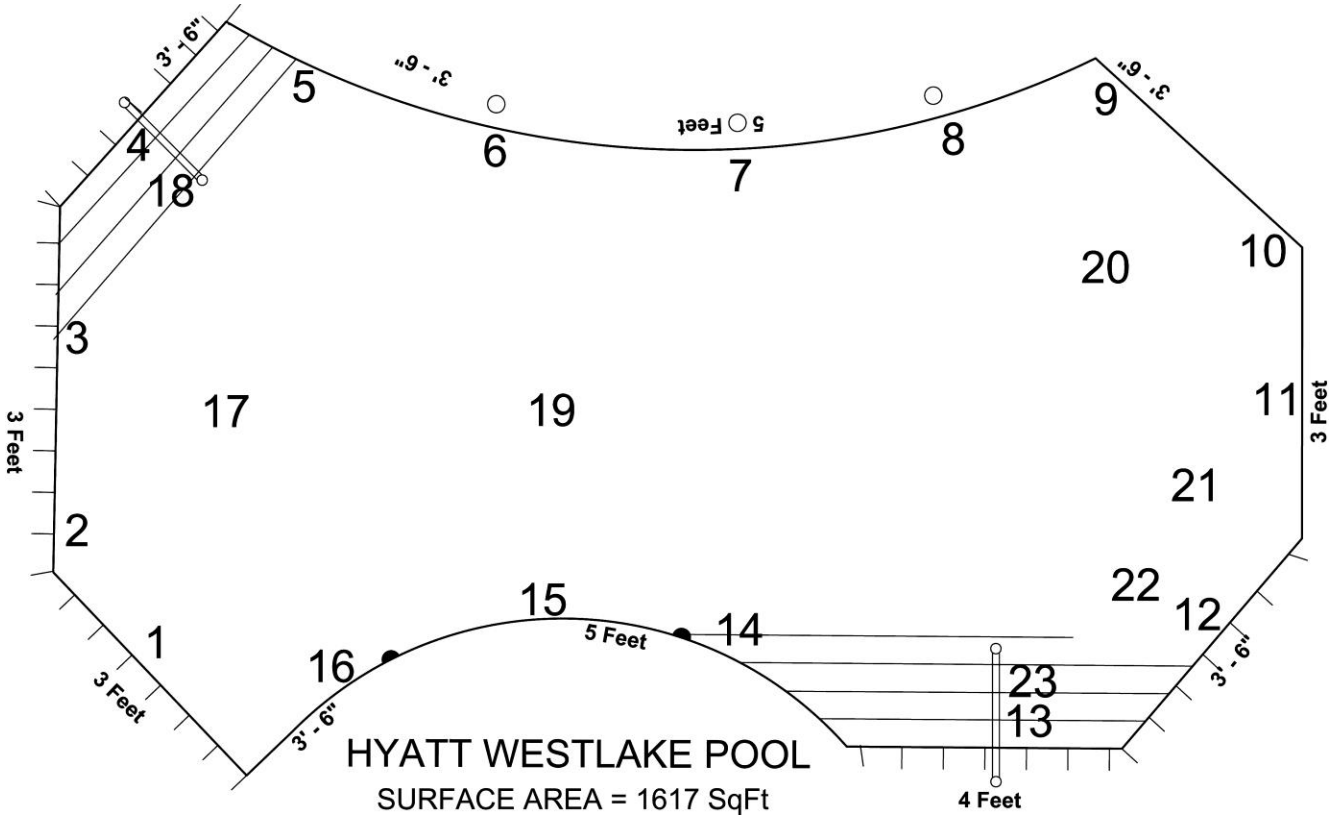
The following table highlights the equipment used in the testing of the LED lighting discussed in this report.

TABLE 35. LED FIELD TEST EQUIPMENT

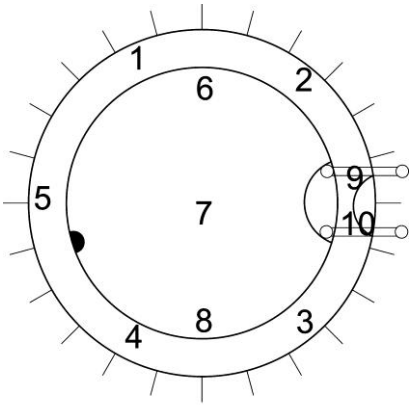
MANUFACTURER	MODEL	CALIBRATION	DESCRIPTION	USED FOR	SPECIFICATIONS
Labsphere	SLMS LED 7650	Monthly	Spectral light measurement system (integrating sphere)	Luminous flux, correlated color temperature, color rendering index	Sphere-spectroradiometer method, 76” diameter, 4pi geometry, 350-850 nm spectroradiometer bandwidth, auxiliary compensation, D65 white point
Hioki	3196	9/17/2010	Power quality analyzer	AC-side electrical logging, voltage, current, power, frequency, power factor, current THD	RMS voltage +/-0.2% AC, Frequency +/-10mHz, +/- 1 digit from the calculation, more specifications at www.hioki.com
LI-COR	LI-210, LI-1400	9/4/2010 Update	Photometric Sensor, Handheld data logger	Illuminance (lux)	Absolute Calibration: ± 5% traceable to NIST, Sensitivity: Typically 30 µA per 100 klux, Linearity: Maximum deviation of 1% up to 100 klux, Stability: < ± 2% change over a 1 year period, Response Time: 10 µs, Temperature Dependence: ± 0.15% per °C maximum, Cosine Correction: Cosine corrected up to 80° angle of incidence, Azimuth: < ± 1% error over 360° at 45° elevation, more specifications at www.licor.com
Minolta	T10W	08/14/2010	Photometric Sensor, Handheld data logger	Illuminance (lux)	0.1-200,900 lux 0.001-29,990 fc +/-2%
Onset	HOBO U22-001	New	Temperature Logger	Data logging pool water temperature	Operation range – maximum sustained temperature of 50°C (122°F) in water, Accuracy - 0.2°C over 0°C, Response time – 5 minutes in water, more specifications at www.onsetcomp.com
Micro Data Logger	202	Never	Data Logger	Logging operating hours of the pools	NA

APPENDIX C – NIGHTTIME SURVEYS BY SITE & LOCATION

Hyatt Westlake Village Pool and Spa



HYATT WESTLAKE POOL						
LAMP TYPE		INCANDESCENT	LED	DIFFERENCE	LED	DIFFERENCE
MANUFACTURER			LED Luminaire E		LED Luminaire B	
LOCATION		FOOTCANDLES				
POSITION	MARKER					
V	1	0.97	5.59	4.62	0.94	-0.03
V	2	1.96	6.95	4.99	1.85	-0.11
V	3	2.31	4.51	2.20	1.86	-0.45
V	4	3.80	3.47	-0.33	1.75	-2.05
V	5	2.54	2.54	0.00	1.08	-1.46
V	6	2.04	4.34	2.30	1.94	-0.10
V	7	2.05	6.24	4.19	2.48	0.43
V	8	4.13	4.07	-0.06	2.22	-1.91
V	9	1.61	2.43	0.82	1.17	-0.44
V	10	0.95	2.07	1.12	0.95	0.00
V	11	0.68	1.62	0.94	0.68	0.00
V	12	0.36	0.98	0.62	0.37	0.01
V	13	0.30	0.66	0.36	0.29	-0.01
V	14	1.08	1.86	0.78	0.86	-0.22
V	15	0.68	1.50	0.82	0.72	0.04
V	16	1.06	2.36	1.30	0.82	-0.24
H	17	1.28	1.63	0.35	1.21	-0.07
H	18	1.14	1.24	0.10	0.82	-0.32
H	19	0.74	2.55	1.81	0.91	0.17
H	20	0.43	0.65	0.22	0.38	-0.05
H	21	0.24	0.79	0.55	0.32	0.08
H	22	0.14	0.39	0.25	0.19	0.05
H	23	1.24	1.91	0.67	0.68	-0.56
AVERAGE (V)ERTICAL		1.66	3.20	1.54	1.25	-0.41
AVERAGE (H)ORIZONTAL		0.74	1.31	0.56	0.64	-0.10

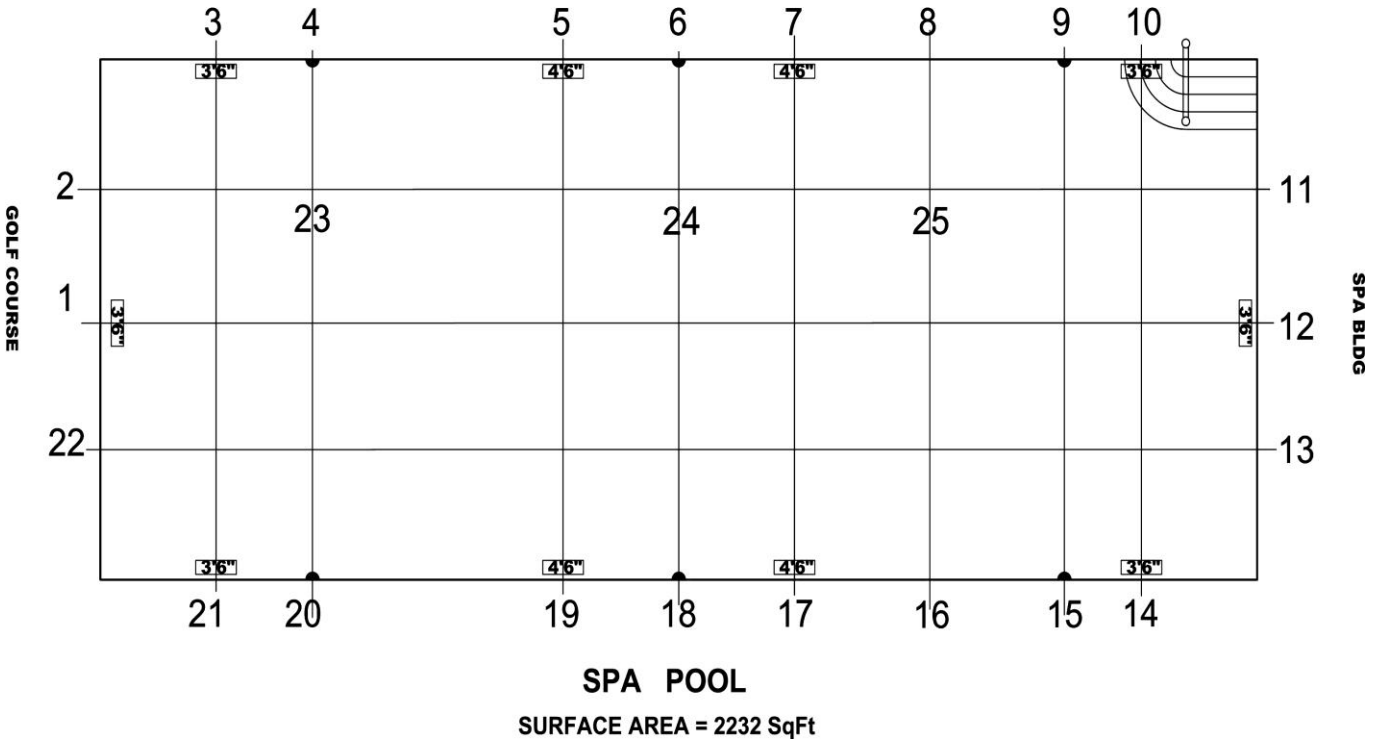


HYATT WESTLAKE SPA

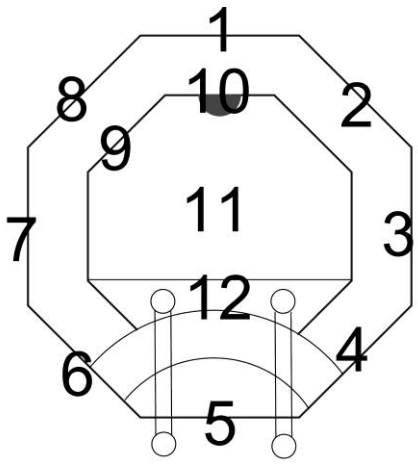
SURFACE AREA = 148 SqFt

HYATT WESTLAKE JACUZZI						
LAMP TYPE		INCANDESCENT	LED	DIFFERENCE	LED	DIFFERENCE
MANUFACTURER			LED Luminaire E		LED Luminaire B	
LOCATION		FOOTCANDLES				
POSITION	MARKER					
V	1	5.54	5.71	0.17	2.70	-2.84
V	2	10.71	8.71	-2.00	5.91	-4.80
V	3	6.92	6.42	-0.50	4.05	-2.87
V	4	4.73	4.27	-0.46	2.26	-2.47
H	5	2.46	2.64	0.18	1.32	-1.14
H	6	11.52	9.30	-2.22	3.91	-7.61
H	7	18.56	11.15	-7.41	5.83	-12.73
H	8	7.63	10.32	2.69	5.18	-2.45
H	9	8.81	5.20	-3.61	8.20	-0.61
V	10	19.53	9.84	-9.69	- - -	
AVERAGE (V)ERTICAL		9.49	6.99	-2.50	3.73	-5.76
AVERAGE (H)ORIZONTAL		9.80	7.72	-2.07	4.89	-4.91

Marriott Desert Springs Resort Spa Pool and Jacuzzi



MARRIOTT SPA POOL				
LAMP TYPE		INCANDESCENT	LED	DIFFERENCE
MANUFACTURER		LED Luminaire C		
LOCATION		FOOTCANDLES		
POSITION	MARKER			
V	1	3.73	4.32	0.59
V	2	2.94	4.44	1.50
V	3	3.12	2.86	-0.26
V	4	3.26	4.16	0.90
V	5	2.99	3.34	0.35
V	6	3.74	3.85	0.11
V	7	2.54	3.13	0.59
V	8	2.59	3.02	0.43
V	9	5.87	3.80	-2.07
V	10	2.52	2.63	0.11
V	11	1.24	1.72	0.48
V	12	2.94	4.78	1.84
V	13	2.84	4.28	1.44
V	14	2.09	4.67	2.58
V	15	2.38	2.79	0.41
V	16	3.76	3.57	-0.19
V	17	2.49	2.94	0.45
V	18	2.61	3.17	0.56
V	19	4.54	3.94	-0.60
V	20	2.76	3.42	0.66
V	21	4.72	3.64	-1.08
V	22	3.01	3.44	0.43
V	23	3.36	5.02	1.66
H	24	3.52	2.99	-0.53
H	25	4.20	5.10	0.90
H	26	1.62	3.01	1.39
AVERAGE (V)ERTICAL		3.13	3.61	0.47
AVERAGE (H)ORIZONTAL		3.11	3.70	0.59



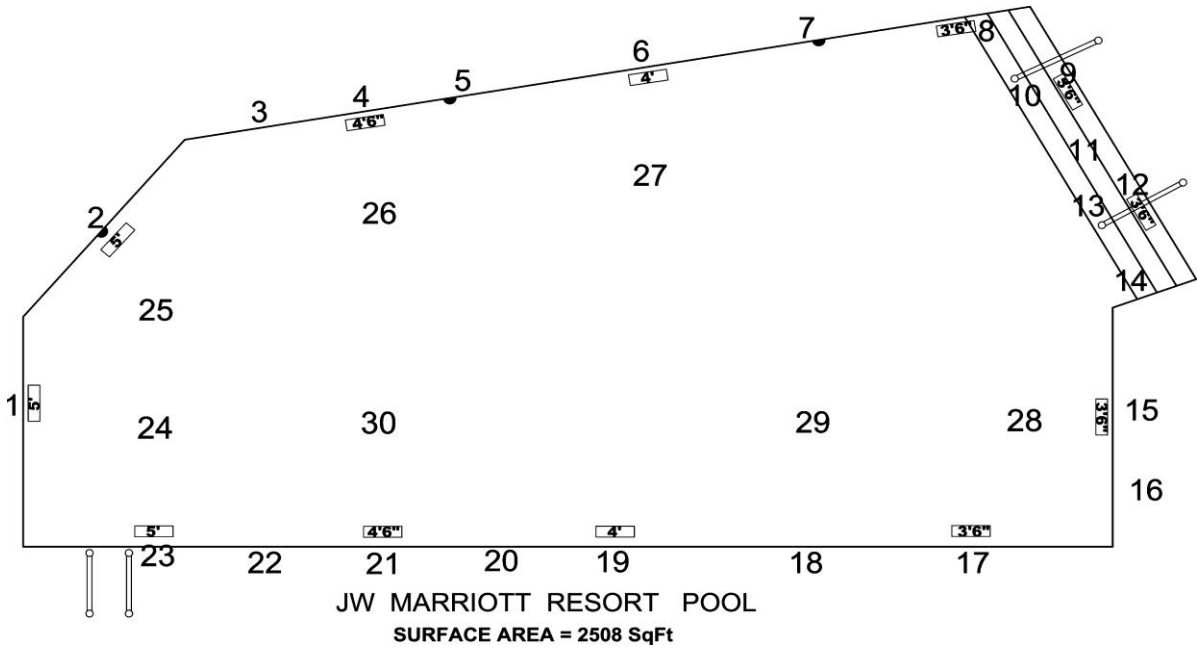
SPA JAQUZZI

SURFACE AREA = 53 SqFt

MARRIOTT SPA JACUZZI				
LAMP TYPE		INCANDESCENT	LED	DIFFERENCE
		LED Luminaire C		
LOCATION		FOOTCANDLES		
POSITION	MARKER			
V	1	4.80		
V	2	4.60	6.35	1.75
V	3	4.80	5.94	1.14
V	4	10.50	7.60	-2.90
H	5	10.50	6.00	-4.50
V	6	11.50	10.87	-0.63
V	7	4.75	6.07	1.32
V	8	4.90	6.64	1.74
H	9		4.75	
H	10	2.72		
H	11	83.30	119.90	36.60
V	12	53.50		
AVERAGE (V)ERTICAL		12.42	7.98	-4.43
AVERAGE (H)ORIZONTAL		32.17	43.55	11.38

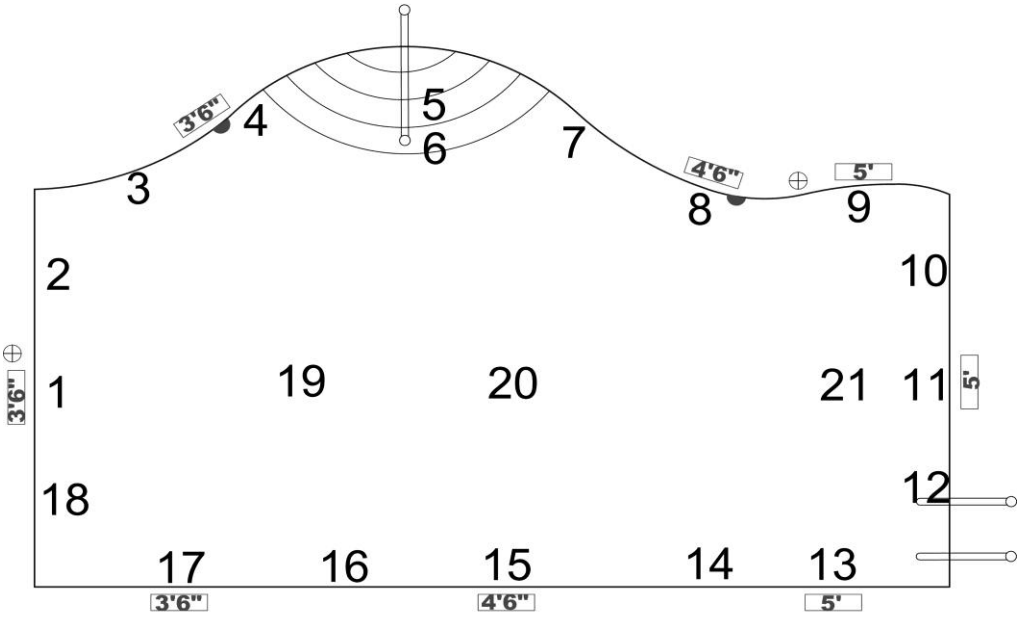
Data Points Not Recorded

Marriott Desert Springs Resort Lap Pool



MARRIOTT HOTEL POOL				
REVISED 11-15-2010				
LAMP TYPE		INCANDESCENT	LED	DIFFERENCE
MANUFACTURER			LED Luminaire B	
LOCATION		FOOTCANDLES		
POSITION	MARKER			
V	1	0.68	0.68	0.00
V	2	1.22	1.44	0.22
V	3	0.57	0.64	0.07
V	4	0.63	0.79	0.16
V	5	1.06	1.53	0.47
V	6	0.38	0.46	0.08
V	7	5.04	3.33	-1.71
V	8	0.33	0.32	-0.01
H	9	0.09	0.12	0.03
H	10	0.24	0.29	0.05
V	11	0.48	0.53	0.05
H	12	0.11	0.12	0.01
H	13	0.21	0.26	0.05
V	14	0.76	0.97	0.21
V	15	0.54	0.71	0.17
V	16	0.49	0.63	0.14
V	17	0.78	0.83	0.05
V	18	1.08	1.21	0.13
V	19	1.39	1.58	0.19
V	20	1.66	1.76	0.10
V	21	1.97	2.08	0.11
V	22	2.12	2.45	0.33
V	23	1.72	2.10	0.38
H	24	0.42	0.79	0.37
H	25	1.35	2.19	0.84
H	26	1.38	2.02	0.64
H	27	0.54	0.63	0.09
H	28	0.22	0.25	0.03
H	29	0.28	0.29	0.01
H	30	0.58	0.58	0.00
AVERAGE (V)ERTICAL		1.21	1.27	0.06
AVERAGE (H)ORIZONTAL		0.49	0.69	0.19

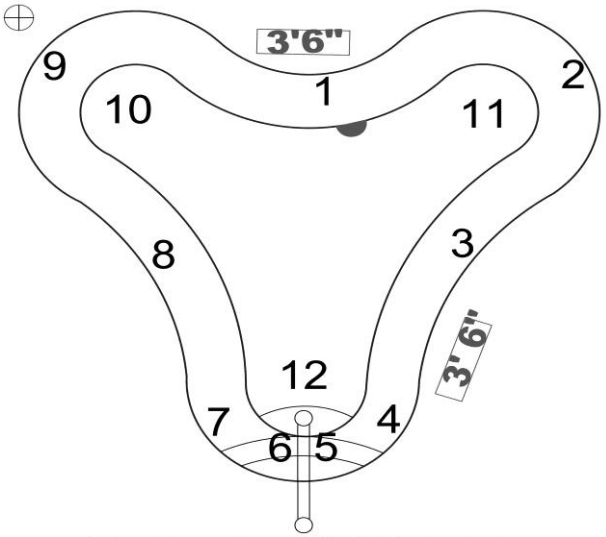
Marriott Desert Springs Villas Cassia Pool and Spa



DESERT SPRINGS VILLAS CASSIA POOL

SURFACE AREA = 948 SqFt

VILLAS CASSIA POOL				
LAMP TYPE		INCANDESCENT	LED	DIFFERENCE
MANUFACTURER		LED Luminaire D		
LOCATION		FOOTCANDLES		
POSITION	MARKER			
V	1	1.96	3.12	1.16
V	2	2.02	2.95	0.93
V	3	1.89	2.69	0.80
V	4	5.12	4.10	-1.02
V	5	1.15	3.24	2.09
V	6	3.60	2.42	-1.18
V	7	1.72	3.62	1.90
V	8	4.29	4.62	0.33
V	9	0.98	1.38	0.40
V	10	1.75	2.19	0.44
V	11	2.00	3.70	1.70
V	12	2.15	3.34	1.19
V	13	3.00	4.26	1.26
V	14	5.20	6.02	0.82
V	15	5.40	5.56	0.16
V	16	5.15	5.27	0.12
V	17	3.75	4.18	0.43
V	18	1.84	2.72	0.88
H	19	2.40	2.56	0.16
H	20	2.25	3.26	1.01
H	21	2.24	2.20	-0.04
AVERAGE (V)ERTICAL		2.94	3.63	0.69
AVERAGE (H)ORIZONTAL		2.30	2.67	0.38



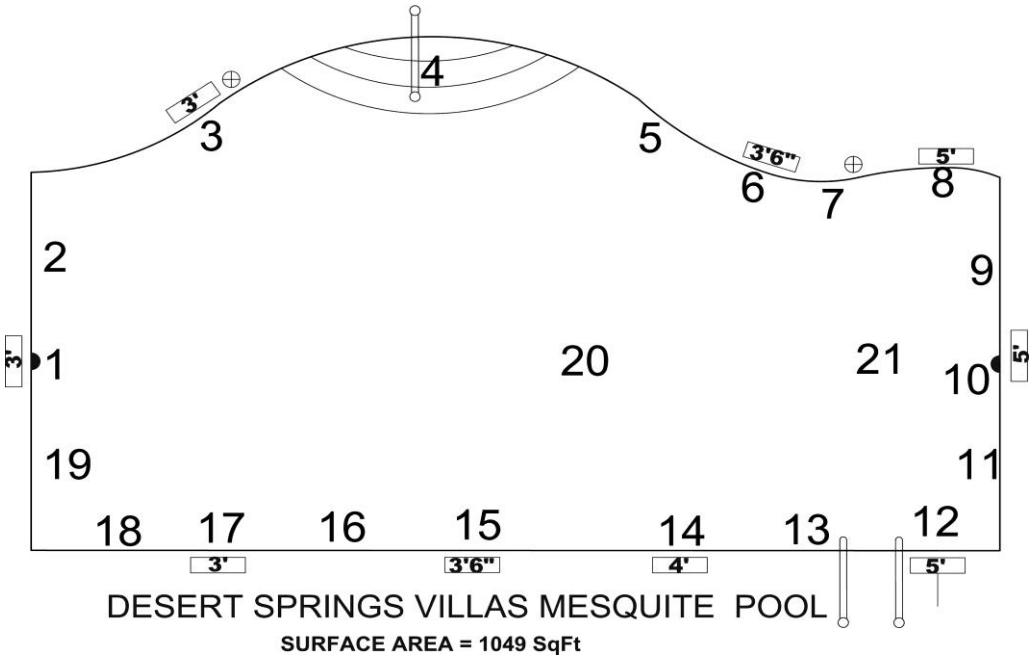
CASSIA JACUZZI

SURFACE AREA = 154 SqFt

VILLAS CASSIA JACUZZI				
		INCANDESCENT	LED	DIFFERENCE
MANUFACTURER		LED Luminaire D		
LOCATION		FOOTCANDLES		
POSITION	MARKER			
V	1	5.65	5.25	-0.40
V	2	4.60	4.22	-0.38
V	3	17.20	7.70	-9.50
V	4	12.60	7.75	-4.85
H	5	5.05	4.20	-0.85
V	6		10.81	
V	7	10.80	7.12	-3.68
V	8	15.10	10.16	-4.94
V	9	3.95	3.86	-0.09
H	10	2.10	2.28	0.18
H	11	2.30	2.64	0.34
H	12	9.80	6.40	-3.40
AVERAGE (V)ERTICAL		9.99	7.11	-2.88
AVERAGE (H)ORIZONTAL		4.81	3.88	-0.93

Data Points Not Recorded

Marriott Desert Springs Villas Mesquite Pool

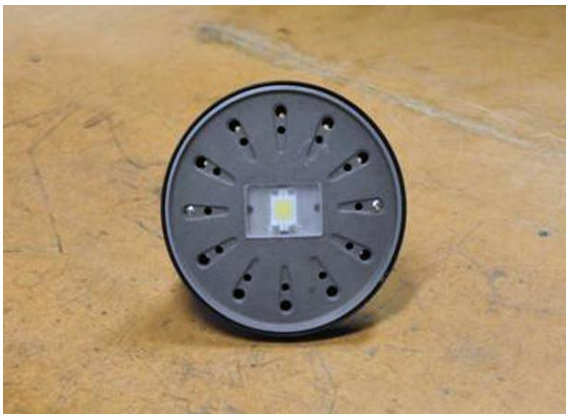


VILLAS MESQUITE POOL				
REVISED 11-15-2010				
LAMP TYPE		INCANDESCENT	LED	DIFFERENCE
MANUFACTURER			LED Luminaire D	
LOCATION		FOOTCANDLES		
POSITION	MARKER			
V	1	12.00	3.20	-8.80
V	2	2.29	0.56	-1.73
V	3	2.18	0.66	-1.52
V	4	1.71	0.47	-1.24
V	5	1.85	0.47	-1.38
V	6	1.81	0.45	-1.36
V	7	3.67	1.05	-2.62
V	8	2.25	0.69	-1.56
V	9	1.84	0.54	-1.30
V	10	3.67	1.12	-2.55
V	11	2.28	0.58	-1.70
V	12	2.38	0.74	-1.64

V	13	4.51	1.08	-3.43
V	14	2.86	0.74	-2.12
V	15	2.00	0.55	-1.45
V	16	2.89	0.74	-2.15
V	17	4.68	1.10	-3.58
V	18	3.39	1.02	-2.37
V	19	2.23	0.58	-1.65
H	20	1.23	0.37	-0.86
H	21	4.90	1.18	-3.72
AVERAGE (V)ERTICAL		3.18	0.86	-2.32
AVERAGE (H)ORIZONTAL		3.07	0.78	-2.29

APPENDIX D – IMAGES OF LED LAMPS TESTED

LED Luminaire A



LED Luminaire B

LED Luminaire C, D, and E

[1] Attachment - LifeCycleCost.xls


LifeCycleCost.xls