Pacific Gas and Electric Company

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Emerging Technologies Program

Application Assessment Report # 0716

LED Low-Bay Garage Lighting
San Francisco, California

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Preface

Energy Solutions provided monitoring, data collection, and data analysis services for an LED Parking Structure Lighting Demonstration Project under contract to the Emerging Technologies Program of Pacific Gas and Electric Company. The project replaced two-lamp linear fluorescent fixtures of 60 watts with new low bay LED fixtures from LEDPower of 25 watts and 5,500K color temperature to determine if a 50% reduction in energy consumption was possible.

Acknowledgements

This project was funded by the Emerging Technologies Program of Pacific Gas and Electric Company. Energy Solutions would like to gratefully acknowledge the direction and assistance of Pacific Gas and Electric Company, LEDPower, and the San Francisco Hilton for their participation and support of this project.

Executive Summary

The LED Low-Bay Garage Lighting Demonstration project studied the applicability of LED fixtures in a parking-garage installation. Linear fluorescent fixtures were replaced with new LED fixtures in a parking garage located at the Hilton in San Francisco. The lowest wattage LED fixtures available were installed to determine if a 50% reduction in energy consumption was possible. Light quality and intensity, and electrical power measurements were taken and economic costs were estimated.

The average illuminance level was decreased after the installation of the LED fixtures. The maximum uniformity ratio (a ratio of the brightest spot to the dimmest) increased, suggesting a less uniform light spread.

TABLE ES-I: ILLUMINANCE LEVELS

Measured Circuits	Average Illuminance (fc)	Max Illuminance (fc)	Min Illuminance (fc)
Demonstration Area 1 Pre-Installation	3.6	14.1	0.33
Demonstration Area 1 Post-Installation	2.2	11.1	0.18
Demonstration Area 2 Pre-Installation	9.7	16.8	3.2
Demonstration Area 2 Post-Installation	5.7	11.6	2.1

An average LED fixture drew 25 watts, 5 watts less than an average linear fluorescent lamp (30 watts). For this application, one LED fixture replaced two linear fluorescent lamps. This resulted in final savings of 35 watts per two-lamp linear fluorescent fixture replaced.

TABLE ES-II: POTENTIAL DEMAND AND ENERGY SAVINGS

Fixture Type	Average Power (W)	Power Savings (W)	Annual Energy Savings (kWh)
Two- Lamp Linear Fluorescent	60	-	-
LED	25	35	307
Full Garage (310 LED Fixtures)	7,750	10,850	95,046

The LED fixtures were assumed to require no maintenance over the course of their expected useful life (50,000 hours, or 5.7 years with continuous operation). When maintenance and replacement costs for linear fluorescent fixtures were combined with energy costs, the LED fixtures cost approximately $22 less per year to operate than a two-lamp fluorescent fixture. In a new construction setting, where the LED fixture is installed in place of a two-lamp linear fluorescent fixture, the total incremental cost is $360 per fixture replaced. In a retrofit setting, the incremental cost is $525 per fixture replaced.

TABLE ES-III: ESTIMATED SIMPLE PAYBACK

	Linear Fluorescent (per Two Lamp Fixture)	LED (1 Fixture)	LED Full Garage (310 Fixtures)
Annual Energy Savings	-	$30.87	$9,569.70
Annual Maintenance Costs	$8.87	-	-
Annual Savings		$39.74	$12,319.40
Incremental Cost (New Construction)	-	$360.00	$111,600
Simple Payback (Years, New Construction)	-	9.06	9.06
Incremental Cost (Retrofit)	-	$525.00	$162,750
Simple Payback (Years, Retrofit)	-	13.21	13.21

For this particular case-study, these payback periods are longer than the 50,000-hour expected useful life of the LED fixtures. To achieve a simple payback of less than 5.7 years under current conditions, the cost of the LED fixture needs to decline to less than $135 in a retrofit scenario or approximately $292 in a new construction scenario.

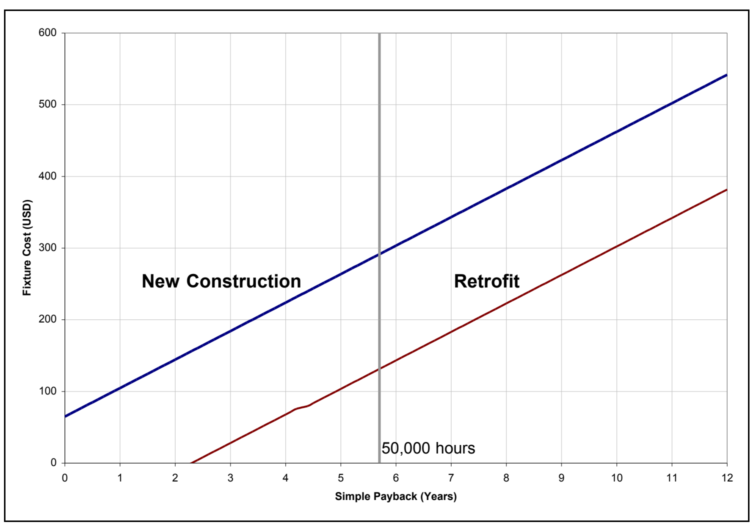

FIGURE ES-1: ESTIMATED LED FIXTURE PAYBACK

Although the results of this assessment indicate a relatively long payback period for LED low-bay garage lighting under current conditions, LED technology is advancing at such a rate as to make these fixtures more economical in the future. This is supported by current trends in LED pricing declines and advancements in LED performance. In addition, utility incentives could help in the short-term to make the fixtures cost-effective for customers, and thus encourage energy savings.

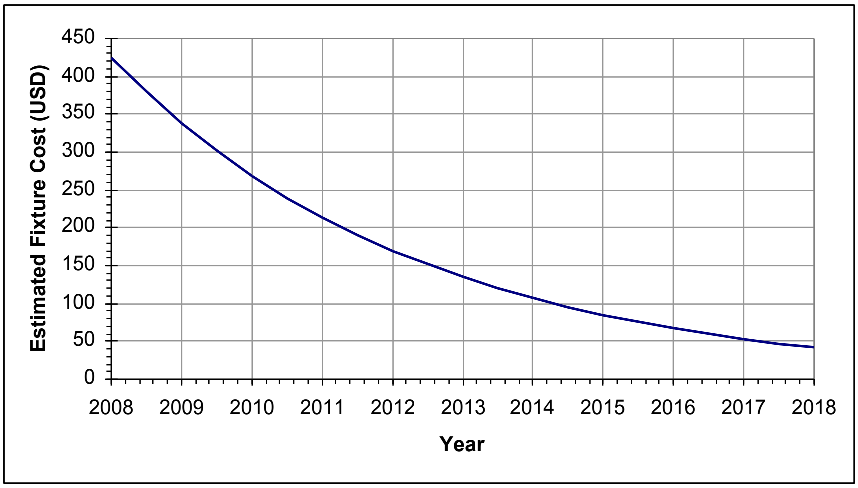

FIGURE ES-2: ESTIMATED FUTURE LED FIXTURE COST[1]

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[1] See 'Economic Performance' section

Project Background

Project Overview

The LED Parking Structure Lighting Demonstration project studied the applicability of light-emitting-diode (LED) fixtures in a parking structure installation. Linear fluorescent fixtures were replaced with new LED fixtures in a parking structure located in San Francisco. The applicability of the technology was determined by light output, energy and power usage, and economic factors. The feasibility of potential future LED fixtures in the same application was also assessed.

The LED Parking Structure Lighting Demonstration project was conducted as part of the Emerging Technologies Program of Pacific Gas and Electric Company. The Emerging Technologies program "is an information-only program that seeks to accelerate the introduction of innovative energy efficient technologies, applications and analytical tools that are not widely adopted in California…. [The] information includes verified energy savings and demand reductions, market potential and market barriers, incremental cost, and the technology's life expectancy."[2]

Technological Overview

At the time of this assessment, LEDs are showing promise in parking structures due to the less stringent requirements for color consistency. Currently, parking structures are normally illuminated with metal halide, high-pressure sodium, or linear fluorescent lights. LEDs have the potential for long life, reduced maintenance, high color rendition, reduced operating cost, and lower energy usage than other technologies. At this time, however, the initial cost of LEDs is much higher than alternative light sources.

Information from the US Department of Energy suggests the technology is changing at a rapid pace. Overall, the performance of LED fixtures seems to be advancing at a rate of approximately 35% annually.[3] Therefore, readers of this assessment are encouraged to note that while this particular demonstration may not have met the host customer's requirements for further investment, advances in this field are occurring so quickly that this or another manufacturer may have a product under development that will soon meet the host customer's performance and investment criteria.

[2] Pacific Gas and Electric Company (2006). Program Descriptions, Market Integrated Demand Side Management, Emerging Technologies. *PGE2011*

[3] Based on lumen output per LED. See 'Economic Performance' section

Market Overview

A report by Navigant Consulting in 2002 estimates that lighting makes up approximately 22% of IOU kWh sales on a national scale. The study further estimates that lighting for parking accounts for roughly 4% of kWh sales for lighting.[4] Using kWh sales figures from a 2006 study, [5] the total consumption in PG&E's service territory for lighting is calculated to be on the order of 21,500 GWh in 2002, with a resulting 860 GWh for parking. Although these figures are not exclusively for parking lot lights, and do not include parking structures that are integrated into other buildings, they give an idea of the significant potential that exists for savings.

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[4] Navigant Consulting, Inc. (2002). "US Lighting Market Characterization, Volume I".

[5] Itron Inc., et al (2006). "California Energy Efficiency Potential Study".

Project Objectives

The objectives of the project were to examine electrical, lighting, and economic performance of LED fixtures as compared to linear fluorescent fixtures in a parking structure application. The potential electrical demand and energy savings were measured in terms of instantaneous wattage and estimated annual kWh usage. Quantitative lighting performance was determined by average illuminance, uniformity, and correlated color temperature (in Kelvin). Qualitative lighting performance was judged by the satisfaction and concerns of interested parties. Finally, economic performance was calculated as simple-payback for substitution in a new construction setting or replacement in a retrofit setting, accounting for fixture life-span, maintenance costs, and electrical costs.

Methodology

Host site information

The facility selected for this demonstration was a private parking structure located at the Hilton in San Francisco, California. The facility contains approximately 310 existing linear fluorescent fixtures and is located completely underground. The test area within the structure was chosen to minimize disruptions to facility operations.

Monitoring Plan

The Monitoring Plan called for initial, pre-installation and post-installation field visits to the parking structure.

The initial field visit was intended for familiarization with the parking structure, and to gather general base-line information.

The pre-installation field visit occurred after initial field visit and prior to installation of the LED fixtures. It was intended to document the existing condition of the lighting system. The linear fluorescent lamps had been replaced as requested by Energy Solutions approximately 6.5 weeks (roughly 1,100 hours of continuous operation) prior to the pre-installation visit. This represents 5.5% of the 20,000 hour rated life of the lamps, corresponding to an estimated 5.5% lumen depreciation.[6]

The parking garage was divided into two test areas, Demonstration Area 1 on the lowest parking level of the garage and Demonstration Area 2 on a driveway incline. All light measurements in Demonstration Area 1 were taken on a 5'x5' grid for the entire test area (the area in which LED fixtures were installed), and on a 2'x2' grid for 20' out from a single fixture. All light measurements on Demonstration Area 2 were taken on a 4'6" x 5'4" grid for the entire test area, and on a 2' x 2' grid for 4' out from a single fixture. For measurement locations and geometry, see Appendix A. Measurements were taken consistent with Appendix B. The specific outcomes of the pre-installation field visit are listed below:

1. Pre-installation on-site photographs, Appendix C.
2. Pre-installation power, illumination and correlated color temperature readings, Appendix D.

The post-installation field visit was intended to document the condition of the lighting system after the installation of the LED fixtures. The post-installation measurements in Demonstration Area 2 were taken approximately 3 weeks (roughly 500 hours of continuous operation) after the equipment installation and the post-installation measurements in Demonstration Area 1 were taken approximately 1 month (roughly 720 hours of continuous operation) after the equipment installation. Burn hours were based on the confirmed installation date and the average daily burn times. The LED fixtures in Demonstration Area 1 were installed approximately 5 inches off center from the linear fluorescent fixtures, due to the presence of piping along the ceiling. Post-installation measurements in Demonstration Area 1 were off set by 5 inches from the pre-

[6] Osram Sylvania (2001). Product Information Bulletin, OCTRON ECOLOGIC".

installation monitoring points to account for this. Specific outcomes of the post-installation field are:

1. Post-installation on-site photographs, Appendix C.
2. Post-installation power, illumination and correlated color temperature readings, Appendix D.

The following monitoring equipment used in the execution of this Monitoring Plan was obtained from the Pacific Energy Center:

LIGHT OUTPUT
Li-Cor Light Meter, Model: LI-250 with LI-COR Photometric Sensor, Model: li-210sa

CORRELATED COLOR TEMPERATURE METER
Konica Minolta Chroma Meter, Model CL-200

POWER METER
Summit Technology Power Sight 3000 Meter (PS3000) kit with Clamp on Voltage Probes, and Clamp-on Current Probes, Model: HA10

Project Results

Electrical Demand and Energy Savings

Power measurements were taken from one-lamp and two-lamp linear fluorescent fixtures at the pre-installation visit and from two LED fixtures at the post-installation visit. Annual energy and savings figures were estimated based on replacing approximately 620 lamps in two-lamp linear fluorescent fixtures on a total of 11 floors. This would correspond to 310 replacement LED fixtures.

The LED fixtures used an average of 25 watts per fixture, equal to the rated wattage. The average installed linear fluorescent fixture used 30 watts per lamp. As a result, the demand savings per replaced fixture was approximately 35 watts, or 11 kW for 310 fixtures.

The garage fixtures are on continuously, amounting to annual savings of 307 kWh per replacement, or 95,046 kWh for 310 fixtures.

TABLE I: MEASURED POWER DEMAND AND ESTIMATED ENERGY USAGE

Measured Circuits	Linear Fluorescent Fixtures	LED Fixtures	Total Power (W)	Annual Energy per Fixture (kWh)
Pre-Installation	2	0	60	525.6
Post-Installation	0	1	25	219

TABLE II: POTENTIAL DEMAND AND ENERGY SAVINGS

Fixture Type	Average Power (W)	Power Savings (W)	Annual Energy Savings (kWh)
2 Lamp Linear Fluorescent	60	-	-
LED	25	35	306.6
310 LED Fixtures	7,750	10,850	95,046

Lighting Performance

ILLUMINANCE

Demonstration Area 1

Illuminance levels were measured on a 5-foot grid for the Demonstration Area 1, and on a 2-foot grid for a detailed test area under a single fixture. The average measured illuminance for the linear fluorescent fixtures was 3.6 foot-candles in Demonstration Area 1, with the LED fixtures decreasing this value to 2.2 foot-candles. The maximum and minimum levels measured for the linear fluorescents in Demonstration Area 1 were 14.1 and 0.33 foot-candles, respectively. The ratio of these two values is known as the uniformity ratio, and in this case is 43:1 for Demonstration Area 1. The Illuminating Engineering Society of North America recommends a minimum light level of 1 foot-candle and a maximum uniformity ratio for parking garages of 10:1. For the LED fixtures, these values were 11.1 and 0.18 foot-candles, with a poorer uniformity ratio of approximately 63:1. In addition, a "fixture-to-wall" ratio was calculated as the average amount of light along the strip directly under the southern fixtures divided by the average near-wall lighting level. For the linear fluorescent fixtures, the fixture-to-wall ratio was 9.25:1 and for the LED fixtures, this value was and 9.5:1.

TABLE III: ILLUMINANCE LEVELS FOR DEMONSTRATION AREA 1

Measured Circuits	Average Illuminance (fc)	Max Illuminance (fc)	Min Illuminance (fc)	Uniformity Ratio	Average Near- Wall Illuminance (fc)	Fixture-to-Wall Ratio
Pre-Installation	3.6	14.1	0.33	43:1	0.77	9.25:1
Post-Installation	2.2	11.1	0.18	63:1	0.52	9.5:1

Demonstration Area 2

Illuminance levels were measured on a 4'6" x 5'4" grid for Demonstration Area 2, and on a 2-foot grid for a detailed test area. The average measured illuminance for the linear fluorescent fixtures was 9.7 foot-candles, with the LED fixtures decreasing this value to 5.7 foot-candles. The maximum and minimum levels measured for the linear fluorescents in were 16.8 and 3.2 foot-candles, respectively. The uniformity ratio in this case is 21:4. For the LED fixtures, these values were 11.6 and 2.1 foot-candles, with a slightly worse uniformity ratio of approximately 11:2. A fixture-to-wall ratio was not calculated for Demonstration Area 2, due to interference from surrounding light at the edge of the demonstration area.

TABLE IV: ILLUMINANCE LEVELS FOR DEMONSTRATION AREA 2

Measured Circuits	Average Illuminance (fc)	Max Illuminance (fc)	Min Illuminance (fc)	Uniformity Ratio
Pre-Installation	9.7	16.8	3.2	21:4
Post-Installation	5.7	11.6	2.1	11:2

FIGURE 1: AREA 1 PRE-INSTALLATION LIGHTING MEASUREMENTS (LUX)

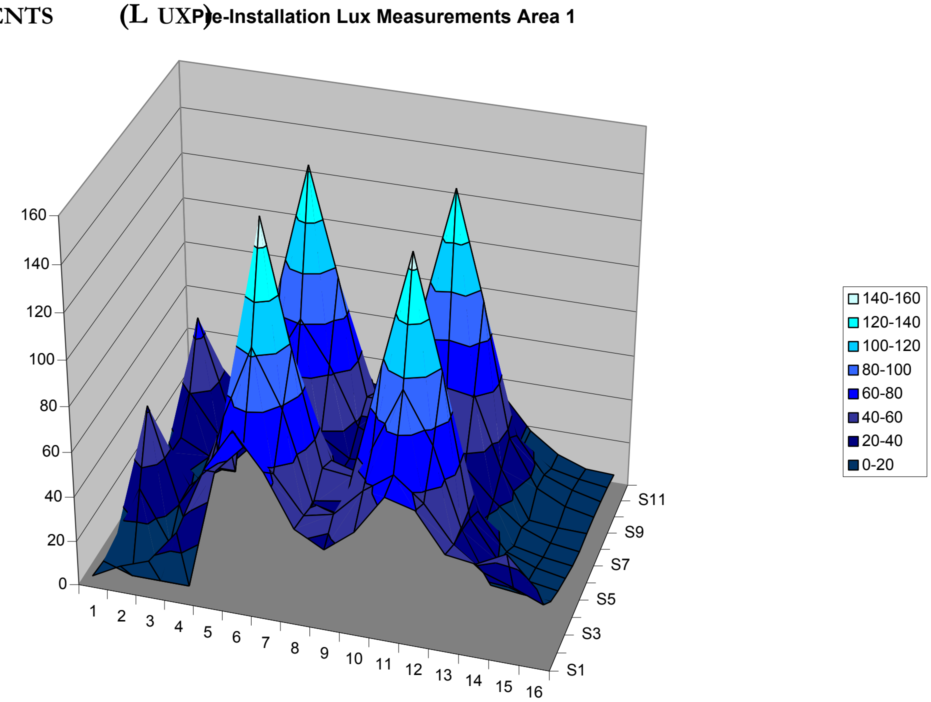


FIGURE 2: AREA 1 POST-INSTALLATION LIGHTING MEASUREMENTS (LUX)

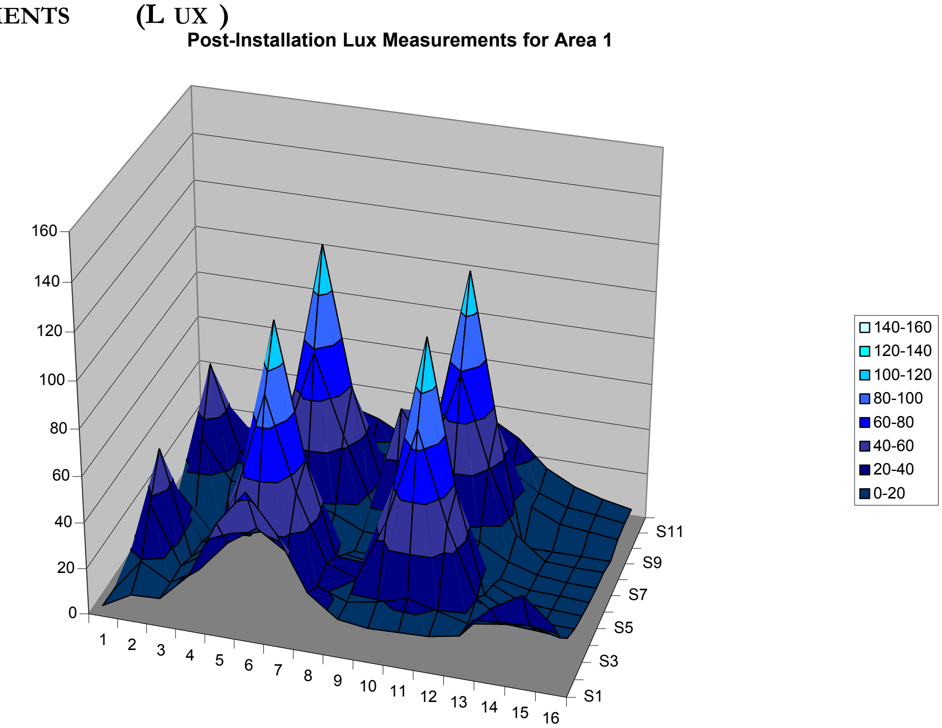


FIGURE 3: AREA 2 PRE-INSTALLATION LIGHTING MEASUREMENTS (LUX)

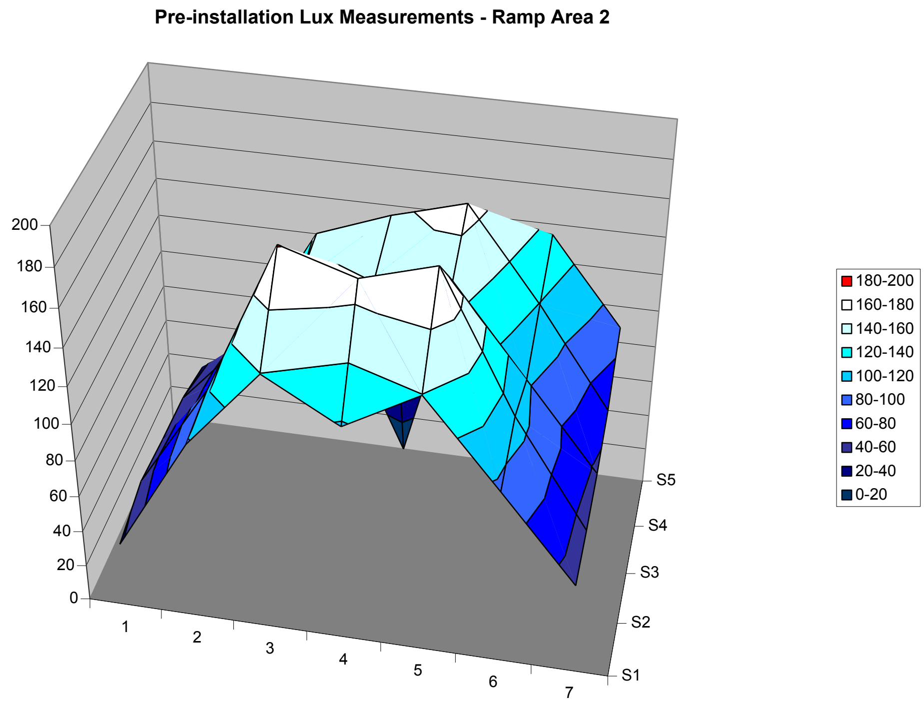
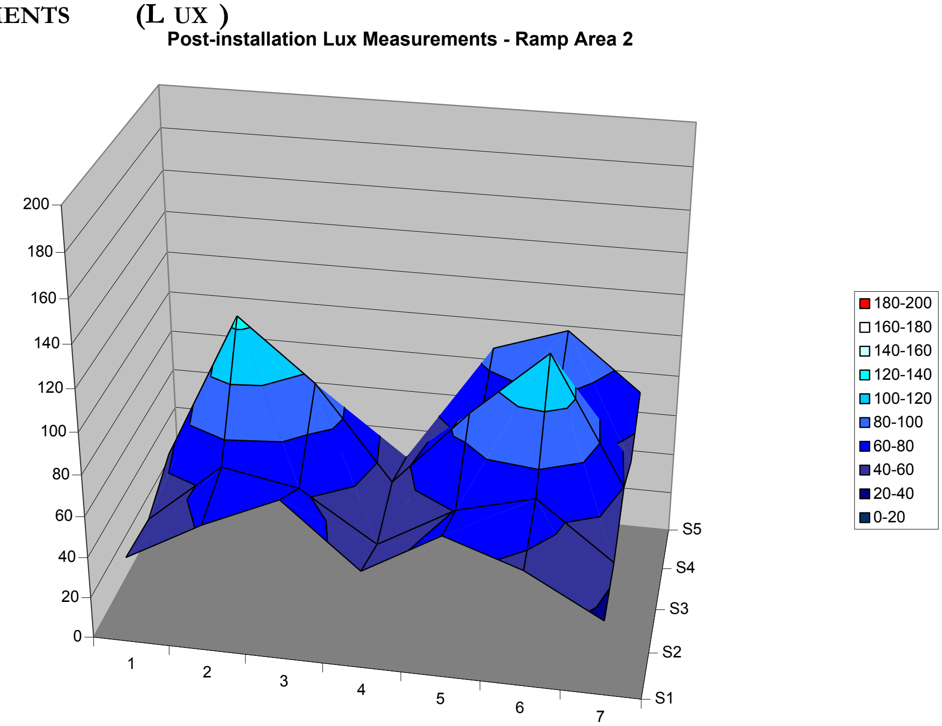


FIGURE 4: AREA 2 POST-INSTALLATION LIGHTING MEASUREMENTS (LUX)



CORRELATED COLOR TEM PERATURE

The average correlated color temperature directly under the linear fluorescent lamps was 3675 K, within a range of 3622 to 3707K. The color temperature of the LED fixtures was measured as 5970K.

CUSTOMER ACCEPTANCE

The host customer has design and construction standards for lighting at their facilities. For parking structures, the lighting standard specifies an illumination range of 2 to 5 foot-candles in parking slots and 10 to 15 foot-candles in drive aisles. The LED fixtures do not provide adequate illumination to meet this standard in the drive aisles or in the parking slots. However, it should be noted that the pre-installation measurements indicate the linear fluorescent fixtures do not meet the lighting standard in all areas of the parking garage.

The garage parking staff and the Chief Engineer for the San Francisco Hilton also provided feedback on the qualitative performance of the LED fixtures. Overall, the parking staff was not pleased with the LED fixtures and felt that the lighting level from the LED fixtures was too low. The parking staff felt that the new lighting made it difficult to drive safely in the parking garage and did not feel safe when going to and from vehicles. The staff preferred the lighting level under the linear fluorescent fixtures. The Chief Engineer did not see the LED fixtures as a big improvement over the linear fluorescent fixtures, but did feel that the LED fixtures would be a good choice for a new installation.

Economic Performance

Economic performance was evaluated primarily by simple payback of the LED fixtures versus the linear fluorescent fixtures. To calculate this, current energy and materials costs were assumed while taking into account maintenance cost and energy cost. The host customer's reported energy cost is on average $0.09 per kWh.

Maintenance costs for linear fluorescent fixtures were calculated on an annualized basis, assuming fluorescent lamps are replaced upon burnout, approximately once every 20,000 hours. This is based upon the host customer's maintenance protocols.

Due to uncertainties in future LED fixture costs, LED fixture replacement was not incorporated into maintenance estimates. Normally this cost could be annualized, effectively saving money each year toward eventual fixture replacement. Since this was not done, if a fixture has a calculated simple payback period longer than its useful life, it will not have recouped the initial investment.

Two economic scenarios were evaluated: a new-construction scenario and a retrofit scenario. In the new-construction scenario, the LED fixtures are assumed to be installed in place of linear fluorescent fixtures. In the retrofit scenario, the LED fixtures are assumed to replace linear fluorescent fixtures upon planned replacement.

TABLE IV: ANNUAL FIXTURE COSTS

	Annual Maintenance Cost	Annual Energy Cost	Total Annual Cost
Linear Fluorescent (per Fixture)	$8.87	$52.93	$80.67
LED (1 Fixture)	$0	$22.05	$22.05
Linear Fluorescent (310 Fixtures)	$2,749.70	$16,408	$25,007
LED (310 Fixtures)	$0	$6,836	$6,836

TABLE V: NEW CONSTRUCTION ECONOMICS

	Initial Investment	Incremental Cost	Annual Savings	Simple Payback (Years)
Linear Fluorescent (per Fixture)	$165.00	--	--	--
LED (1 Fixture)	$525.00	$360.00	$39.74	9.06
Linear Fluorescent (310 Fixtures)	$51,150	--	--	--
LED (310 Fixtures)	$162,750	$111,600	$12,319.40	9.06

TABLE VI: RETROFIT ECONOMICS

	Initial Investment	Incremental Cost	Annual Savings	Simple Payback (Years)
Linear Fluorescent (per Fixture)	--	--	--	--
LED (1 Fixture)	$525.00	$525.00	$39.74	13.21
Linear Fluorescent (310 Fixtures)	--	--	--	--
LED (310 Fixtures)	$162,750	$162,750	$12,319.40	13.21

For the linear fluorescent fixtures, maintenance accounted for roughly fifteen percent of the total annual cost, with energy costs accounting for the remaining eighty-five percent. As previously noted, maintenance costs for the LED fixtures were effectively assumed to be zero, so the energy costs accounted for 100% of the annual cost.[7] This is because the only predicted maintenance for the LED fixtures was eventual fixture replacement due to lumen depreciation.

Cost curves were generated showing requisite LED fixture costs for simple paybacks under 10 years with the existing replacement factor of one LED fixture for two linear fluorescent lamps.

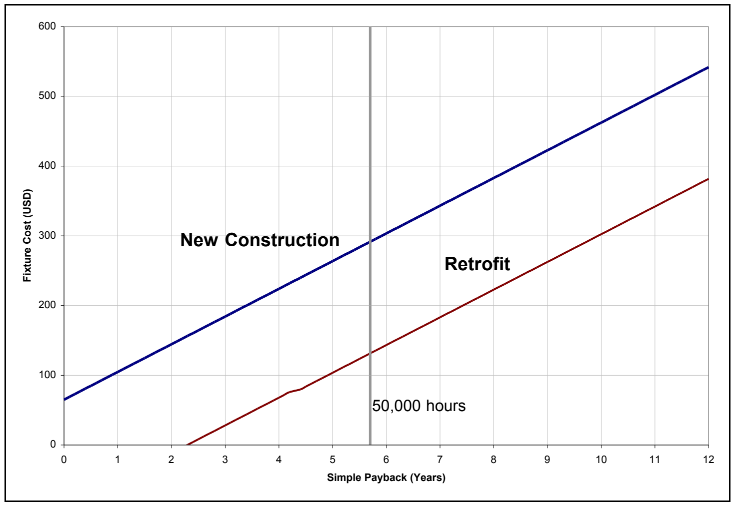


FIGURE 4: ESTIMATED FIXTURE PAYBACK (ASSUMING NO MAINTENANCE)

If the LED fixtures are to be replaced at the current price of $425 at the end of their rated life (every 50,000 hours), the annualized maintenance cost is approximately $93 per year per fixture. This increases the annual cost of the fixtures more than five fold, causing the annual cost of the LED fixtures to be greater than that of the linear fluorescent fixtures. The main factors driving this high annual maintenance cost is the cost of the LED fixture.

Haitz's Law predicts that the light output of LEDs increases by a factor of 20 every 10 years, while the cost decreases by a factor of 10 over the same period of time. This has held approximately true since the late 1960's.[8] If fixture cost is assumed to decrease at a rate consistent with Haitz's law, the LED fixture cost in late 2013 (the end of their rated life, if installed now) would be approximately $135. The annualized cost of replacement would then be roughly $41.17/year, which combined with annual energy costs would still exceed the annual cost to operate linear fluorescent fixtures.[9]

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[7] See Appendix E1. 1,2

[8] Steele, Robert V (2006). "The story of a new light source." Nature Photonics 1, 25 – 26. *10.1038/nphoton.2006.44*

[9] See Appendix E2

In recent years technological improvements have begun to exceed the pace of Haitz's law. If this remains the case, the price of the LED fixture may decrease such that the LED fixture replacement has a more favorable simple payback.

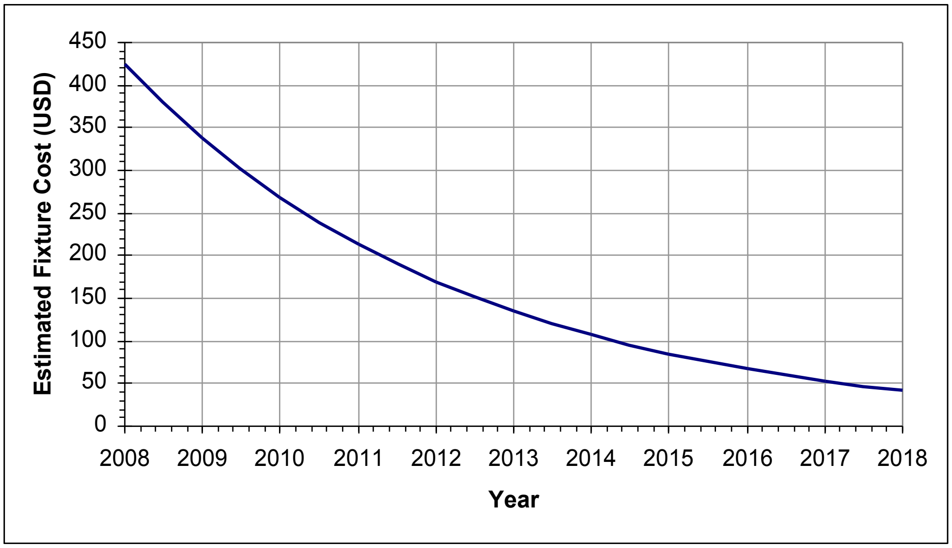


FIGURE 6: ESTIMATED FIXTURE COST [10]

[10] Steele (2006).

Discussion

The installed 25 watt LED fixtures did not provide sufficient general illumination to meet the host customer's lighting specifications in this demonstration project. In Demonstration Area 1 one two-lamp linear fluorescent fixture was replaced with 1 LED fixture and in Demonstration Area 2 two one-lamp linear fluorescent fixtures were replaced with 1 LED fixture. The LED fixtures provided a slight overall decrease in illumination, as well as decrease in uniformity, over the linear fluorescent fixtures. The power required by the LED fixtures to provide this illumination, with the 2-for-1 replacement, was less than that of the linear fluorescent fixtures. It should be noted that a 2006 study indicated that a lens optic can be effectively used to provide greater light dispersion, potentially addressing this problem.[11] Additionally, lighting distribution will vary in situations where the arrangement or installation of the fixtures is different from this particular application.

Despite the energy savings of the LED fixtures, the fixture costs in this case were such that they were not economical as judged by simple payback. In order to achieve a 2-year simple payback during new construction, these fixtures could cost a maximum of around $145, or $264 for a 5-year payback. These simple paybacks do not include any maintenance costs for the LED fixtures.

Advancements in LED efficacy will also aid in improving the economic performance of LED fixtures by increasing energy savings. With the rapid development of LED technology, this is not out of the realm of possibility in the relatively near-term. Utility incentive programs could help to bring the price down to this level for the consumer even sooner.

[11] Peck, John P. and C. Vishno Shastry (2006). "LED Light fixture for parking garages." Proc. Of SPIE Vol. 6337. *63371D*

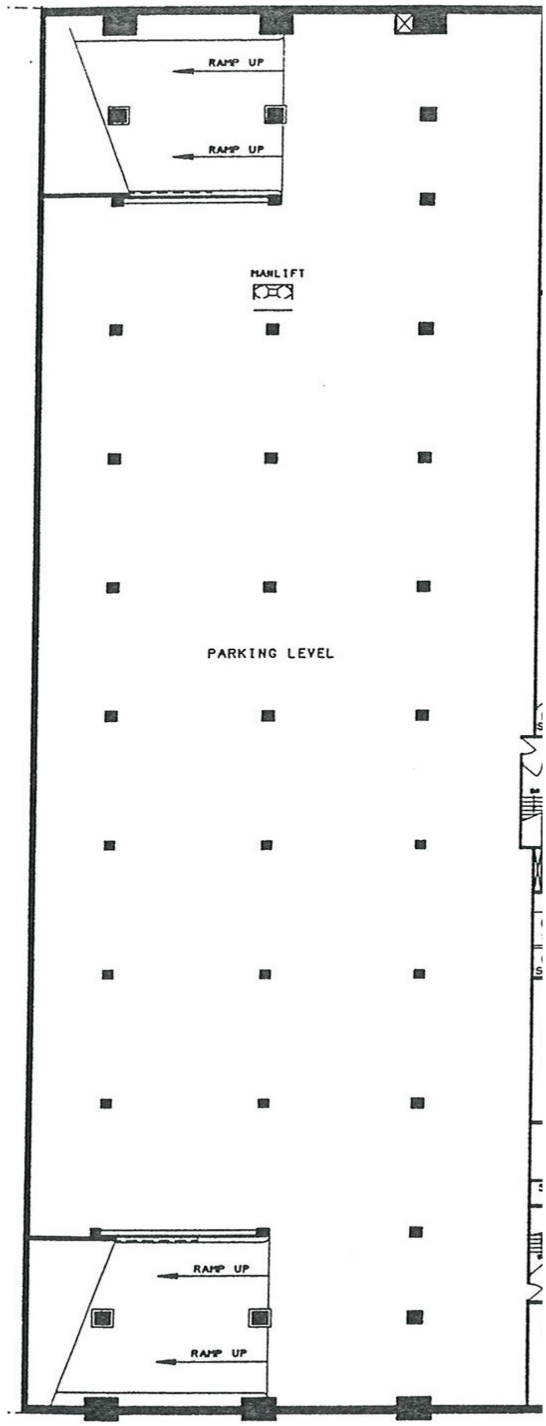
Conclusion

LED lighting, such as that demonstrated in this project, has potential for energy savings. Although the specific fixtures tested in this project did not prove an economic replacement for the previously installed linear fluorescent fixtures, the economic viability of LED fixtures in general is continually improving as the technology advances. Further consumer adoption of LEDs for general lighting could also provide a positive feedback cycle with technology advancement, as more research money is invested. Utility incentive programs, if they are able to bring prices down to an economical level for consumers, have the potential to help spur this cycle.

Appendix A: Facility and Monitoring Layout

APPENDIX A1: FACILITY AND MONITORING LAYOUT

Figure A1.1: Floor-Plan and Measurement Layout of Testing Area.



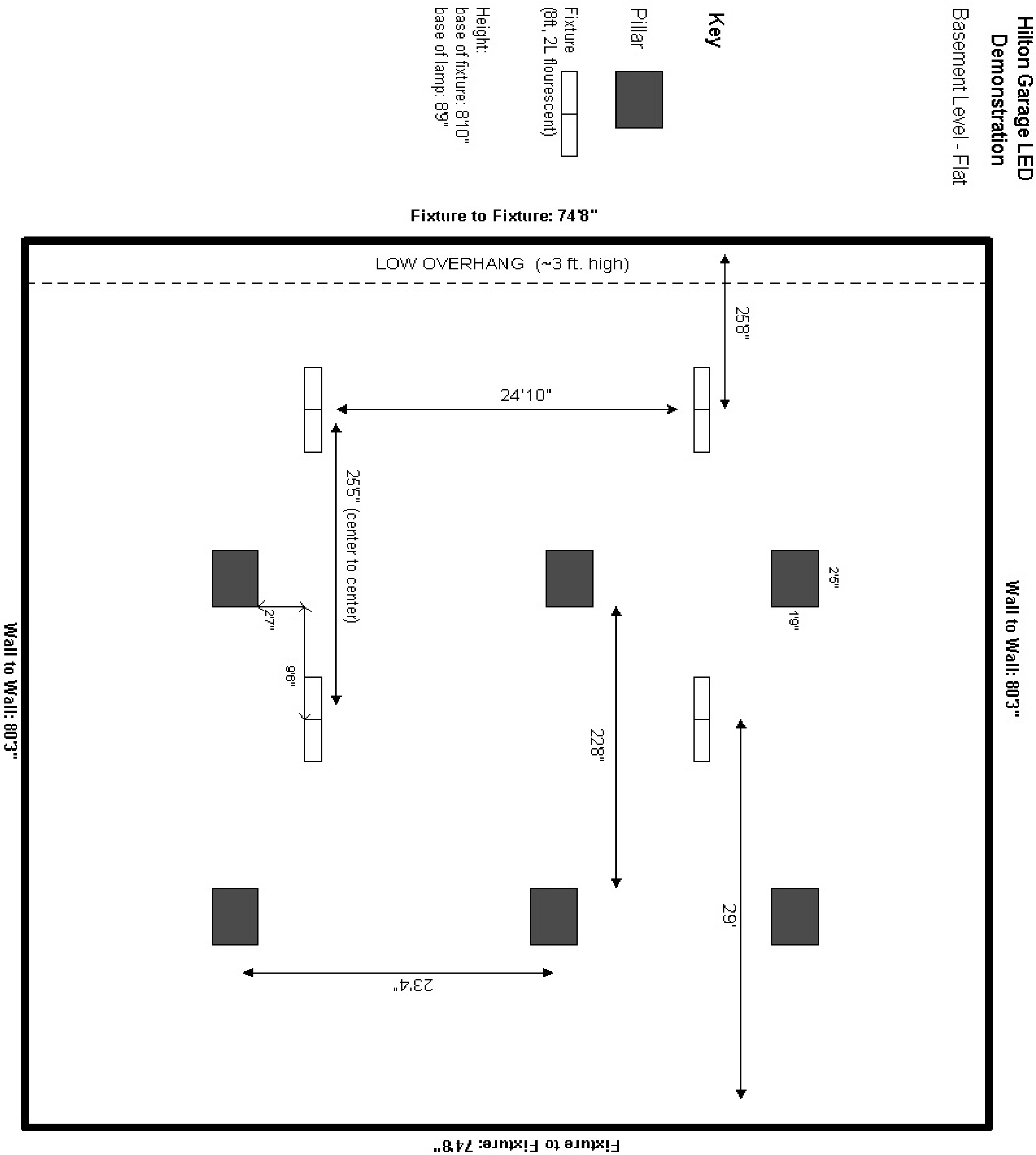


Figure A1.2: Measurement Layout of Demonstration Area 1.

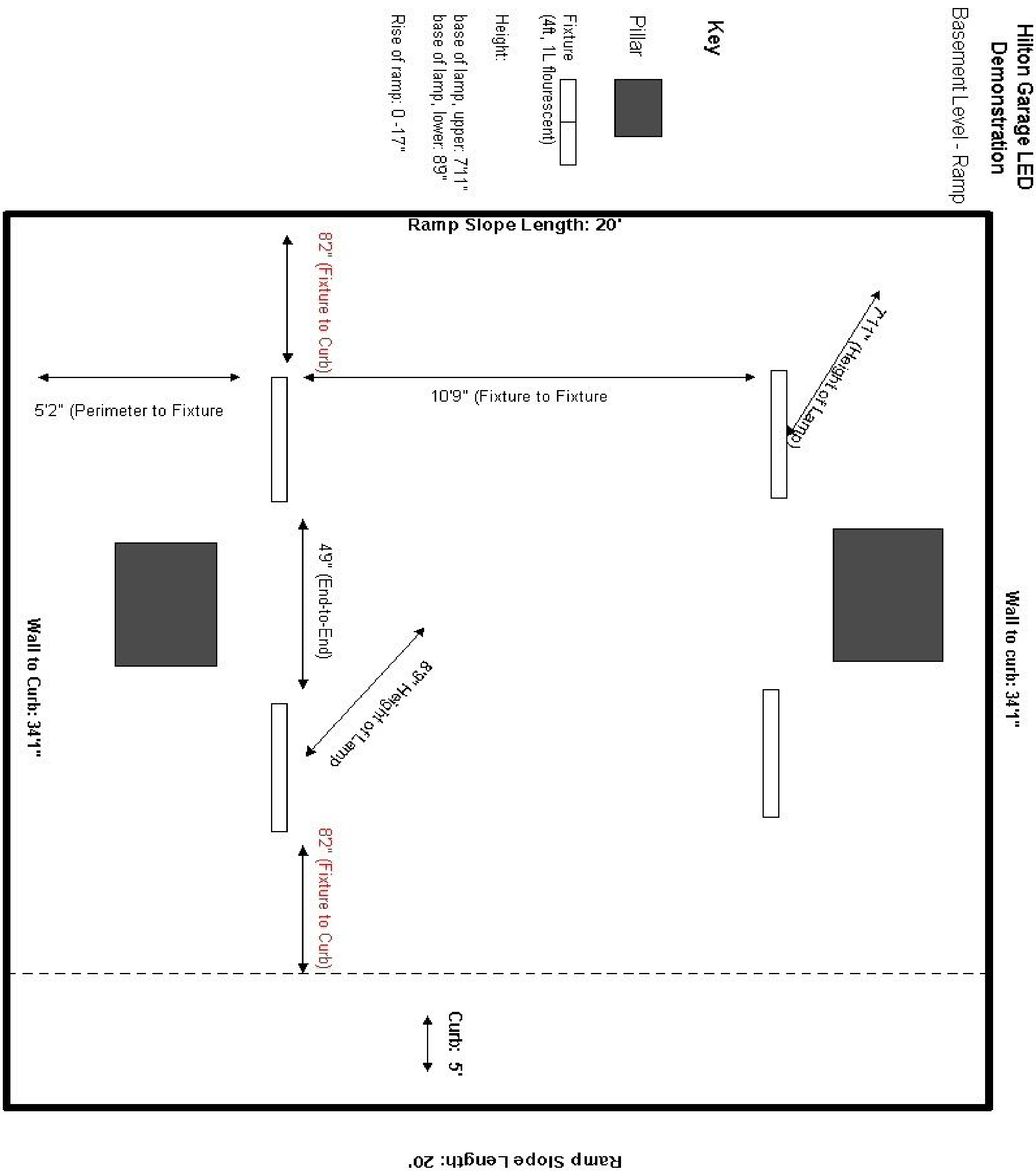


Figure A1.3: Measurement Layout of Demonstration Area 2.

APPENDIX A2: FIXTURE LOCATIONS

Table A2.i: Estimated Fixture Locations, Area 1.

Fixture Number (clockwise from fixture at –X,-Y)	Reference Point
1	F9
2	F4
3	K9
4	K4

Table A2.ii: Estimated Fixture Locations, Area 2.

Fixture Number (clockwise from fixture at –X,-Y)	Reference Point
1	C4
2	C2
3	E4
4	E2

Appendix B: Data Collection Form

Low Bay Parking Garage LED Fixture
Field Collection Form

Location: San Francisco Hilton Parking Garage

Page: 1 of 3

Pre-installation date ________

Post-installation date ________

Light Status Meter ________

Light Output Meter ________

Power Meter ________

FIXTURE	FOOTCANDLES				CCT	PF	AMPS	NOTES
Type	Horizontal Reading Under fixture at ground	Horizontal Reading at end of parking bay at ground	Horizontal Reading midway Between Fixtures at ground	Vertical Reading at parking bay wall at 4 Feet	Of Light In Space	Single Fixture	Single Fixture	
Fixture Type 1: Pre-installation Value Post-installation Value Delta Value								Kim Lighting PGL4 Sylvania M175/U/Med
Fixture Type 2: *Description* Pre-installation Value Post-installation Value Delta Value								

LIGHTING CIRCUIT	AMPS	PF
Circuit 1 Pre-installation Value Post-installation Value Delta Value		
Circuit 2 Pre-installation Value Post-installation Value Delta Value		

FIXTURES DETAIL	QTY	NOTES
Circuit 1		
Fixture 1		
Fixture 2		
Circuit 2		
Fixture 1		
Fixture 2		

Appendix C: Site Photographs

APPENDIX C1: PRE-INSTALLATION PHOTOGRAPHS

APPENDIX C2: POST-INSTALLATION PHOTOGRAPHS

Appendix D: Monitoring Data

APPENDIX D1: PRE-INSTALLATION DATA

APPENDIX D1.1: POWER DATA

Table D1.1.i: Averaged Pre-installation Power Measurements. (Measured with Summit PS3000 and HA-1000, last calibrated 6/9/2007)

Demonstration Area	Linear Fluorescent Fixtures	LED Fixtures	Voltage (v)	Current (a)	Power (w)	Power Factor
1 (Garage Floor)	2	0	120.1	0.49	59	0.98
2 (Ramp)	1	0	120.7	0.25	31	0.96

APPENDIX D1.2: CORRELATED COLOR TEMPERATURE DATA

Table D1.2.i: Pre-installation Correlated Color Temperature Measurements. (Measured with Minolta CL-200, last calibrated 7/24/2006)

Demonstration Area 1 (Garage Floor)

Ambient Conditions	Measurement Location	Color Temperature (K)
Daytime	F4	3707
Daytime	F9	3680
Daytime	K4	3689
Daytime	K9	3701

Demonstration Area 2 (Ramp)

Ambient Conditions	Measurement Location	Color Temperature (K)
Daytime	C2	3622
Daytime	C4	3648

APPENDIX D1.3: ILLUMINATION DATA

Table D1.3.i: Illumination over Demonstration Area 1 (Garage Floor). (In lux; measured with Minolta CL-200, last calibrated 7/24/2006 and LI-COR LI-250 with PHOTOMETRIC, calibrated against Minolta CL-200)

	Reference Coordinates (ft)	**A** -25	**B** -20	**C** -15	**D** -10	**E** -5	**F** 0	**G** 5	**H** 10	**I** 15	**J** 20	**K** 25	**L** 30	**M** 35	**N** 40	**O** 45	**P** 50
1	40	5.4	12.2	16.9	32.2	62.3	81.6	65.8	43.1	36.2	46.4	64	60.5	43.6	41.8	48.6	35.4
2	35	4.3	car	car	car	54.1	67.2	57.8	41.5	44.4	57.1	66.3	56.1	40.2	30.2	25.8	20.6
3	30	3.6	32.4	9.2	26.6	71.3	103.3	78.3	39.2	36.2	68.6	95.9	73.9	39	16.6	15.1	14
4	25	6.2	62.4	20.3	39.1	39.5	151.7	97.6	47.8	46.3	96.9	146.9	98.5	36.7	19.4	13	10.9
5	20	6.5	41.7	21	32.5	66.6	95.5	72.7	44	40.2	67.2	90.5	65.9	32.3	16.1	11.2	8.7
6	15	6.5	26.9	16.3	24.6	37.8	44.4	37	31.3	27.2	30.3	31.4	25.4	18.4	11.1	8.3	6.6
7	10	6.3	26.5	20.2	22.4	34.1	42.2	38.2	30.1	30.6	36.7	42	35.2	22.2	12.1	7.1	5.4
8	5	6.3	40.4	22.9	30.3	59.4	82	63.5	37.6	31.9	59.6	33.8	60.9	29.2	7.8	6.5	6.2
9	0	7.3	67.8	28.7	34.8	91.5	142.6	95.9	44.2	44.1	91	141.9	95.2	36.3	15.2	8.9	6.2
10	-5	7.3	45.7	26.6	29.7	60.4	88.6	67.8	39.1	38.6	64.8	86.5	64.3	30.1	14	9.1	5.9
11	-10	5.5	24.7	19.8	19.5	29.3	34	29	26.1	24.4	29	30.8	27.4	18.2	9.6	6.9	5.1
12	-15	4.6	13.5	15.1	18.5	29	35.5	29	26.2	27.5	34.7	40.8	32.5	18	9	4.4	3.8

Green highlighted cell indicates location of fixture

Midpoint Measurements

1) Between H4 and I4: 39.6
2) Between K6 and K7: 32.2
3) Dead Center, between H6, H7, I6, I7: 26.1

Table D1.3.ii: Illumination over Demonstration Area 2 (ramp). (In lux; measured with Minolta CL-200, last calibrated 7/24/2006; ambient temperature 68˚F)

	Reference Coordinates (ft)	A -9	B -4.5	C 0	D 4.5	E 9	F 13.5	G 18
1	16	35.7	97.6	139.7	118.1	139.6	95.1	49.6
2	10.666	44.2	100.9	180.7	168.8	179.8	108.6	51.6
3	5.333	41.7	83.3	139.4	147.1	149.8	102.9	56.1
4	0	40.5	80.5	142.9	156.8	167.4	119.4	66
5	-5.333	34.2	59.9	82.6	column	139.7	134.4	88.2

Green highlighted cell indicates location of fixture

Table D4.i: Illumination over Detailed Test Area 1. 20 X 20 ft. grid. (In lux; proposed to measure with Minolta CL-200)

	Reference Coordinates (ft)	A -10	B -8	C -6	D -4	E -2	F 0	G 2	H 4	I 6	J 8	K 10
1	10	22.7	27.6	32.2	37.1	41.5	33.9	33.5	41.3	37.6	33.8	31.4
2	8	25.1	31.1	38.4	46	52.5	55.5	54.7	50.3	41.3	38.2	34.1
3	6	27.2	35.3	46	58.5	68.1	72.9	71.6	63.2	52.2	43.4	37.8
4	4	31.6	43.4	59.9	79.3	95.3	103.2	98.4	81.7	63.1	48	column
5	2	34.7	49.6	71.8	99.5	120.5	130.3	122.8	62.2	78.1	58.5	44
6	0	35	51.9	76.2	107.1	132	141.6	133.4	109.3	80.2	57.2	43.7
7	-2	33.3	47.4	70.1	99.2	119.6	132.8	125.9	103.6	76.5	55.4	39.4
8	-4	29.8	42.4	59.6	79.2	95.7	102.2	99.8	86.8	67.9	52.8	42.8
9	-6	27.5	37	48.1	60.3	70.8	75.9	73.2	65.4	53.5	44.9	37.4
10	-8	25.3	32.5	39.9	47.7	53.8	56.9	53.1	48.6	43.3	38.2	34.4
11	-10	19.6	22.9	26.9	30.3	32.1	33.5	32.8	31	29.5	27.8	25

Table D4.ii: Illumination over Detailed Test Area 2. 4X4 ft. grid. (In lux; proposed to measure with Minolta CL-200)

	Reference Coordinates (inches)	A -48	B -24	C 0	D 24	E 48
1	48	96.1	120.8	140.7	146.6	147.6
2	24	95.1	121.2	141.9	143.5	135.8
3	0	92.8	117.8	139.3	145.7	154.2
4	-24	78.6	102.5	121.8	128.6	129.8
5	-48	50	56.1	66.1	column	column

APPENDIX D2: POST-INSTALLATION DATA

APPENDIX D2.1: POWER DATA

Table D2.1.i: Post-installation Power Measurements. (Measured with Summit PS3000 and HA-1000, last calibrated 6/9/2007)

Demonstration Area	Linear Fluorescent Fixtures	LED Fixtures	Voltage (v)	Current (a)	Power (w)	Power Factor
1 (Garage Floor)	0	1	122.3	0.2	25	No reading available
2 (Ramp)	0	1	122.3	0.2	25	No reading available

APPENDIX D2.2: CORRELATED COLOR TEMPERATURE DATA

Table D2.2.i: Post-installation Correlated Color Temperature Measurements. (Measured with Minolta CL-200, last calibrated 7/24/2006)

Demonstration Area 1

Ambient Conditions	Measurement Location	Color Temperature (K)
Daytime	F9	5790

Demonstration Area 2

Ambient Conditions	Measurement Location	Color Temperature (K)
Daytime	C4	5790

APPENDIX D2.3: ILLUMINATION DATA

Table D2.3.i: Illumination over Entire Test Area. (In lux; measured with Minolta CL-200, last calibrated 7/24/2006 and LI-COR LI-250 with PHOTOMETRIC, calibrated against Minolta CL-200)

	Reference Coordinates (ft)	A -25	B -20	C -15	D -10	E -5	F 0	G 5	H 10	I 15	J 20	K 25	L 30	M 35
1	40	4.8	11.8	12.4	24.5	49.3	64.7	49	26	16.7	15	15.5	16	[illegible]
2	35	4.5	19.4	12.2	20.1	33.9	42.5	34.2	21.7	16.9	19.2	23	19.7	[illegible]
3	30	4.7	37.6	12.5	20.8	49.6	92.5	53.1	24.5	20.3	46.8	88.2	49.6	[illegible]
4	25	4.2	55.1	9.4	19.5	57.9	117	59.9	20.4	19.7	58.2	119.4	57	[illegible]
5	20	3.5	33.6	9.1	13.2	26.2	37.1	26.5	14.2	12.6	25.9	37.6	25.5	[illegible]
6	15	2.3	20.7	6.1	7.3	11.4	14	11.3	8.6	7.9	11.3	13.7	10.5	
7	10	1.9	car	car	car	15.6	20.4	16.2	10.5	9.9	15.1	18.7	14.3	
8	5	3.2	33.3	16.2	14.3	39.8	78.5	44.6	15.7	60.2	41.4	79.1	41.6	[illegible]
9	0	4.4	60	22.3	16.5	54.8	119	59.2	20.4	20.3	53.6	116.6	53.4	car
10	-5	4.1	39.3	18.2	13.7	27.5	39.4	28.9	16.6	17.4	20.5	40	28.1	[illegible]
11	-10	3.6	20.7	14.5	11	16.6	20	17.8	15.1	15.6	19.7	22.3	18.7	[illegible]
12	-15	3.1	11.3	11.9	14	24	29.8	26.1	19.8	21.2	28.3	34.1	27	[illegible]

Table D2.3.ii: Illumination over Detailed Test Area. (In lux; measured with Minolta CL-200, last calibrated 7/24/2006; ambient temperature 58˚F)

Reference Coordinates (ft)	**A** (-10)	**B** (-8)	**C** (-6)	**D** (-4)	**E** (-2)	**F** (0)	**G** (2)	**H** (4)	**I** (6)	**J** (8)	**K** (10)
1 (10)	24.6	25.1	27.4	29.6	31.8	32.3	32.8	31	26.6	26.2	27
2 (8)	31.3	31.1	35.4	41.6	46.7	48.2	48.3	40.7	34.7	33.6	35.3
3 (6)	42	40.8	48.8	63	80.4	84.7	78.9	62.6	50.2	45.9	49.1
4 (4)	54.9	52.7	67.6	99.1	136.7	150.8	131.8	94.9	67	59.9	68.6
5 (2)	67.37	64.2	89.4	142	213.8	247.6	209.1	136.6	87.3	73.8	89
6 (0)	72.7	69.9	98.9	165.9	260.4	303.2	247.3	153.8	97.2	79.8	97.7
7 (-2)	68.5	64.7	89.2	143.6	221.4	251	211.9	140.2	85	74	88.2
8 (-4)	55.4	53.3	70.8	100.2	142.3	149.1	141.9	102.1	71.5	58.8	70.4
9 (-6)	40.6	40	47	62	80	81.6	81.4	64.6	50.5	44	48.7
10 (-8)	28.4	26.3	32.8	38.5	45.5	43.6	46.6	40.7	33	30.5	33.2
11 (-10)	19.4	18.9	21.1	23.4	24.4	23.9	24.4	24.3	21.8	20.5	21.9

Appendix E: Additional Economic Data

APPENDIX E1: ADDITIONAL ECONOMIC DATA

APPENDIX E1.1: 2-LAMP FLUORESCENT FIXTURE FOR -1 LED FIXTURE REPLACEMENT, NEW CONSTRUCTION

Linear Fluorescent Fixture

Maintenance		
Lamp Replacement		
Replacement Frequency	1 /20,000	hours
Replacement Cost	10.00	$/two-lamps
Replacement Time	0.100	hr/replacement
Pay Rate	35.00	$/hr
Annual Cost	5.91	$/yr
Ballast Replacement		
Replacement Frequency	1 /60,000	hours
Replacement Cost	15.00	$/ballast
Replacement Time	0.150	hr/replacement
Pay Rate	35.00	$/hr
Annual Cost	2.96	$/yr
Total Maintenance Cost:	8.87	$/yr

Energy		
Demand	60.00	w
Monthly Demand Charge	7.8100	$/kW
Annual Cost	5.62	$/yr
Usage	525.60	kWh
Rate	0.0900	$/kWh
Annual Electricity Cost	47.30	$/yr
Total Annual Cost:	52.93	$/yr

TOTAL ANNUAL COST: $61.80

LED Fixtures

Maintenance		
Fixture Installation		
Installation Frequency	0.00	/yr
Installation Cost	425.00	$/fixture
Installation Time	1.00	hr/installation
Pay Rate	100.00	$/hr
Annual Cost	0.00	$/yr
Total Maintenance Cost:	0.00	$/yr

Energy		
Demand	25.00	w
Monthly Demand Charge	7.81	$/kW
Annual Demand Cost	2.34	$/yr
Usage	219.00	kWh
Rate	0.0900	$/kWh
Annual Cost	19.71	$/yr
Total Energy Cost:	22.05	$/yr

TOTAL ANNUAL COST: $22.05

Payback

Initial Installation	165.00	$
Incremental Cost	360.00	$
Annual Savings	39.74	$
Simple Payback	9.06	years
2 Year Payback	144.48	$ Repl. Cost
5 Year Payback	263.70	$ Repl. Cost

APPENDIX E1.2: 2-LAMP FLUORESCENT FIXTURE FOR-1LED FIXTURE REPLACEMENT, RETROFIT

Linear Fluorescent Fixtures

Maintenance		
Lamp Replacement		
Replacement Frequency	1	/20,000 hours
Replacement Cost	10	$/lamp
Replacement Time	0.1	hr/replacement
Pay Rate	35	$/hr
Annual Cost	5.913	$/yr
Ballast Replacement		
Replacement Frequency	1	/60,000 hours
Replacement Cost	15	$/ballast
Replacement Time	0.15	hr/replacement
Pay Rate	35	$/hr
Annual Cost	2.9565	$/yr
Total Maintenance Cost:	8.8695	$/yr

Energy		
Demand	60	w
Monthly Demand Charge	7.81	$/kW
Annual Cost	5.6232	$/yr
Usage	525.6	kWh
Rate	0.0900	$/kWh
Annual Cost	47.304	$/yr
Total Annual Cost:	52.9272	$/yr

TOTAL ANNUAL COST:	$61.80

LED Fixtures

Maintenance		
Fixture Installation		
Installation Frequency	0	/yr
Installation Cost	425	$/fixture
Installation Time	1	hr/installation
Pay Rate	100	$/hr
Annual Cost	0	$/yr
Total Maintenance Cost:	0	$/yr

Energy		
Demand	25	w
Monthly Demand Charge	7.81	$/kW
Annual Cost	2.343	$/yr
Usage	219	kWh
Rate	0.09	$/kWh
Annual Cost	19.71	$/yr
Total Annual Cost:	22.053	$/yr

TOTAL ANNUAL COST	$22.05

Payback

Incremental Cost	525	$
Annual Savings	39.74	$
Simple Payback	13.21	years
2 Year Payback	-11.6505	$ Repl. Cost
5 Year Payback	107.5695	$ Repl. Cost