A Lighting Audit of The University of The West Indies St Augustine Campus

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Abstract: *Many students and staff utilize the facilities of The University of The West Indies St. Augustine campus at night. Inadequate lighting can make the school environment unsafe. This paper documents methodologies and the results of an audit conducted on the campus. The audit was performed to determine the adequacy of the campus lighting. Areas audited were identified via a survey distributed to students of the campus. The illuminance levels were measured at these locations and compared to applicable standards of the Illuminating Engineering Society. The results confirmed that none of the areas evaluated satisfied the lighting levels detailed in the standards. Recommendations and implementation plans accompanied by cost-benefit analyses were developed for each area ensuring the standards are satisfied.*

Keywords: Lighting audit, illuminance measurements, lighting designs, financial assessment, design simulation, implementation plans

1. Introduction

Over 22,000 students and staff use the facilities of The University of The West Indies St. Augustine campus (UWI, 2016). Many of these facilities have existing lighting systems, and some have been recently implemented, while some of the lighting systems may not be suitable. To identify the areas that have insufficient lighting, the lighting systems on campus were reviewed based on standards that recommend lighting levels. Methodologies were reproduced in order to conduct a lighting audit. A project was initiated to audit existing lighting systems to determine the adequacy of the campus lighting. Based on the findings of the audit, recommendations and future implementation plans were identified.

A lighting audit is a process by which lighting systems can be evaluated by comparing these systems to existing standards. The purpose of an audit is to determine the effectiveness of the existing system and determine where improvements can be made. To ensure the existing systems satisfy the specific standard(s) with financial consideration. The recommended changes would improve the safety and comfort of individuals using the campus. Adequate lighting throughout the campus will also improve the sense of security of the university community.

In order to determine areas that may have insufficient lighting, a survey was distributed to the students of the university. The students were broadly asked to identify areas with insufficient lighting. Responses from the students along with university guidance were used to identify areas to be audited. The illuminance levels of these areas were then evaluated. Table 1 shows the types of premises and total area evaluated per different types and the percentage covered for the audit.

Table 1. Different Types of Premises and Total Areas Evaluated for the Lighting Audit

1. Car Parks	Area (m^2)
Heart Ease Car Park	3,516.4 m^2
Trinidad Government Railway (TGR) South Car Park	2,688.6 m^2
Sports and Physical Education Centre (SPEC) Car Park	606 m^2
Dudley Huggins Car Park	826.8 m^2
Sub-total:	7,637.8 m^2
Percentage of car parks evaluated:	17.7 %
2. Roadways	Area
North Entrance Roadways	2,815.3 m^2
SPEC Entrance Roadway	1,799.6 m^2
South Entrance Roadways	1,739.1 m^2
Entrance Roadway Adjacent to Heart Ease Car Park	1,162.8 m^2
Sub-total:	7,516.8 m^2
Percentage of Roadways evaluated:	24.57 %
3. Walkways	Area
Walkway Adjacent to Block 13	1,325.2 m^2
North Entrance Walkway	56.7 m^2
South Gate Entrance Walkway	116.4 m^2
Sub-total:	1,498.3 m^2
4. Field	Area
SPEC Cricket Field	49,577.1 m^2
Percentage of fields evaluated:	29.67 %

This paper reviews available methods used to perform the lighting audit, and provides a comparison of recommended lighting level standards and the chosen methods for carrying out the audit. It reports the main results of the audit, and presents the analysis and recommendations for improving the lighting on campus.

2. Methodology

The method for performing the lighting audit was sub-divided into three (3) main parts, namely 1) determining areas to be audited, 2) data acquisition, and analysis of data.

2.1 Determining areas to be audited

In order to determine areas that may have insufficient lighting, a survey was distributed to the students of the university. The students were broadly asked to identify areas with insufficient lighting. Responses from the students along with university guidance were used to identify areas to be audited.

2.2 Data Acquisition

Data acquisition included performing illuminance measurements on the different areas outlined in the scope. In addition to the illuminance measurements, data was gathered based on the type, wattage, and position of fixtures in the areas being audited. Information such as the fixture wattage was provided by the Division of Facilities Management (DFM). The following describes methods of performing these illuminance measurements. These methods describe how the sample points were determined, as well as the height and orientation of the sensor while taking the measurements.

2.2.1 Measuring Parking Lot Lighting

Richman (2012) suggested a method for measuring parking lot lighting. This method was used to evaluate the illuminance levels of the parking lots on campus, and is described below:

1. The dimensions of the area being evaluated were identified via the ArcGIS web application and by physical measurements.
2. The area was divided into a horizontal grid and measurement points on the surface area were identified.
3. It was ensured that the measurement points were evenly spaced in both directions and the distance between two points was at a maximum of fifteen (15) feet.
4. It was ensured that there existed at least three measurement points between poles in both directions.
5. Vertical planes which represented the vertical lighting in the area were identified. These vertical planes were typically the vertical grids situated directly between two poles.

6. Vertical measurements were taken five (5) feet above the surface of the area being evaluated. These measurements were taken in the two main directions of vehicular travel.
7. Horizontal measurements were taken one meter above the ground at each measurement point.
8. Precautions were taken to ensure that there were no obstacles that may have blocked light from the sensor.
9. Precautions were taken to ensure measurements were not taken during fluctuations in the lighting levels due to obstructive light from passing vehicles.
10. Measurements were recorded.

The method used for non-uniformly illuminated areas or non-illuminated areas are described, as follows:

1. For areas where the poles were not uniformly spaced, an existing row of luminaires that were parallel to the site boundary was identified. The average spacing of these luminaires was used as the basis for setting the measurement grid.
2. In the case where there were no luminaires or none of the luminaires were operational, the grid was developed such that the distance between two points was at a maximum of fifteen (15) feet.
3. The procedure for taking vertical and horizontal measurements remains unchanged.
4. Precautions were taken to ensure that there were no obstacles that may have blocked light from the sensor.
5. Precautions were taken to ensure measurements were not taken during fluctuations in the lighting levels due to obstructive light from passing vehicles.
6. The measured values were recorded.

2.2.2 Measuring Roadway Lighting

For evaluating street lighting a 9-step method advocated by Grieneisen et al. (2006), Bhubaneswar Municipal Corporation (2013) and Parmar (2014) is adopted. These steps are listed below;

1. The area between two light poles was divided into a grid with nine sample points.
2. At the location of the first pole three sample points were equally spaced along the width of the road and sidewalk.
3. Similarly, at the location of the second pole three sample points were equally spaced along the width of the road and sidewalk.
4. The last three sample points were located at the centre of the two poles. These three sample points were equally spaced along the width of the road and sidewalk.
5. If the fixtures on the roadway were not operational or there were an absence of fixtures, a grid layout was still used in order to determine the illuminance values.
6. Measurements were taken horizontally one meter above the ground at each sample point.

7. Precautions were taken to ensure that there were no obstacles that may have blocked light from the sensor.
8. Precautions were taken to ensure measurements were not taken during fluctuations in the lighting levels due to obstructive light from passing vehicles.
9. The measurements were recorded.

2.2.3 Measuring Walkway Lighting

This method was used to evaluate walkways on campus. The steps are as follows:
1. The area was divided into a grid.
2. The size of the grid depended on the dimensions of the walkway and spacing of the poles. The distance between two points was at a maximum of fifteen (15) feet.
3. Horizontal readings were taken one meter above the ground.
4. Vertical readings were taken five feet above the ground in the direction of pedestrian traffic on the walkway.
5. Precautions were taken to ensure that there were no obstacles that may have blocked light from the sensor.
6. The average illuminance was found by taking the sum of the measured values and dividing it by the number of measurements taken.

2.2.4 Measuring Field Lighting

The method used for evaluating the illuminance levels of the cricket field is elaborated as follows:.
1. The dimensions of the field were analysed via the ArcGIS application and by physical measurements.
2. The infield was divided into a grid, such that each subsection had a dimension of 37.16 m^2 (400 ft^2).
3. Based on the analysis of the data gathered for the infield, the outfield was divided into a grid with each subsection having a dimension of 148.645 m2 (1600 ft2).
4. Measurements were taken at the centre of each subsection with the sensor placed one meter above the surface of the field.
5. Precautions were taken to ensure that there were no obstacles that may have blocked light from the sensor.
6. The measured values were recorded.

2.3 Analysis of Data Acquired

The data gathered was used to calculate parameters such as the average illuminance and uniformity ratio. These parameters were then compared to the recommended values outlined in the chosen standards. Based on the comparison, conclusions were made as to whether the area being evaluated met the recommended standard or not.

Standards from multiple organizations were considered for evaluating the lighting levels around campus, however, standards from the Illuminating Engineering Society (IES) were chosen. These standards were chosen since they were more detailed and provided guidelines for design procedures. Table 2 shows the standard chosen for each area.

Table 2. Chosen Standards for Respective Areas

Area	Chosen IES Standard
1) Parking Lots	Lighting for Parking Facilities
2) Roadways	Roadway Lighting
3) Walkways	Roadway Lighting
4) Field	Sports and Recreational Area Lighting

The standard chosen for parking lots was IES RP-20-14 Lighting for Parking Facilities (IES, 2014a). Table 3 shows the reference data of the Parking Lot Standard. The following describes how the data was analysed for different areas.

Table 3. Parking Lot Standard

Parking Lots – All Ages (Asphalt) surfaces		
E_{avg} (lux)	E_{vmin} (lux)	(E_{max}/E_{min})
5	2.5	1.5

where: E_{max} = Maximum Horizontal Illuminance
E_{min} = Minimum Horizontal Illuminance
E_{avg} = Average horizontal illuminance
E_{vmin} = Minimum Vertical Illuminance

$$E_{avg} = \frac{\sum_{i=1}^{n} E_i}{n} \qquad (1)$$

where, E_{avg} = Average horizontal illuminance
E_i = Individual measured illuminance at point (i)
n = Number of samples taken

The uniformity ratio of the Parking Lot was calculated as follows:

$$Uniformity\ Ratio\ _{(Parking\ Lot)} = E_{max} / E_{min} \qquad (2)$$

The standard chosen for evaluation of walkway lighting was Roadway Lighting IES RP-8-14 (IES, 2014b). The average illuminance was calculated using Equation (1) and the uniformity ratio of walkway was calculated as follows (see Table 4):

$$Uniformity\ Ratio\ _{(Walkway)} = E_{avg} / E_{min} \qquad (3)$$

Table 4. Maintained Illuminance Values for Walkways

	E_{avg} (lux)	E_{vmin} (lux)	E_{avg}/E_{min}
Pedestrian Areas	5.0	2.0	4.0

The standard chosen for the evaluation of street lighting was Roadway Lighting IES RP-8-14 (IES, 2014b). The roadways internal to the university were classified as collector roadways. A collector roadway supports the traffic between the major and local streets. The surface of the roadways was classed as R3 which is defined as an asphalt road with dark aggregates and a rough texture after months of usage. The pedestrian

conflict was considered high due to the large number of pedestrians in the area at night (see Table 5).

Table 5. Maintained Illuminance Values for Pedestrian Conflict Areas

Road	Pedestrian conflict area	E_{avg} (lux)	E_{avg}/E_{min}
Collector	High	12	3

In order to attain the average illuminance E_{avg} a weighted sum of the measured values was taken. The weightings are based on an area factor for which the illuminance at that point is considered constant. This method was advocated by Grieneisen et al. (2006) Bhubaneswar Municipal Corporation (2013) and Parmar (2014). The average illuminance of the nine point grid used to measure roadway lighting was determined as follows:

$$E_{avg} = \frac{P1 + P3 + P7 + P9}{16} + \frac{P8 + P2 + P6 + P4}{8} + \frac{P5}{4} \tag{4}$$

Where, P1, P2, P3, P4 P5, P6, P7, P8 and P9 are illustrated in Figure 1.
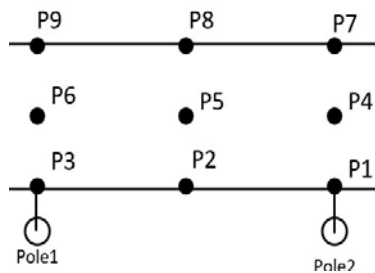
Figure 1. Nine Point Method

If there were an absence of fixtures on the roadway or the fixtures were not operational, the average illuminance can be calculated using Equation (1). The uniformity ratio was calculated using Equation (3).

The standard chosen for evaluating the field lighting was Sports and Recreational Area Lighting IES RP-6-15 (IES, 2015c). The Cricket field was classed as a class II field based on the IES RP-6-15 classification for college facilities. The coefficient of variation (CV) is the ratio of the standard deviation to the mean or average. The equations used to calculate the standard deviation (σ) and CV are:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}\left(E_i - E_{avg}\right)^2}{n}} \tag{5}$$

$$CV = \sigma / E_{avg} \tag{6}$$

The average illuminance and uniformity ratio are determined using Equations (1) and (2), respectively. Table 6 shows a summary of the recommended lighting levels of the field.

Table 6. Recommended Illuminance Levels for Class II Cricket Field

	E_{avg} (lux)	E_{max}/E_{min}	CV
Infield	750	1.5:1	0.1
Outfield	500	2:1	0.17

Where, CV = Coefficient of Variation

3. Development of Recommendations

If the lighting in an area did not meet the recommended standard, this confirms the existing lighting design for that area requires upgrading. These upgrades may be in the form of modifications to existing design or implementation plans for a new design. Modifications may include the implementation of new fixtures on existing poles. Implementation plans for a new design included a new layout of poles with new lighting fixtures.

Since the lighting systems audited could not be modified due to a lack of specifications of the existing fixtures and unevenly spaced poles, new designs were required. Several steps were involved in creating a new lighting design. These are:

1. The area was assessed based on the overall shape and dimensions. Based on the type of area an IES standard was chosen that gave recommended lighting levels for the area. For example, the IES standard entitled Roadway Lighting was chosen for evaluating the roadway lighting.
2. Multiple lighting fixtures applicable to the area were compared. Some of the parameters that were compared are as follows:
   - Defining Technology (e.g. filament, solid state device, low pressure discharge, etc.)
   - Output power (units = W)
   - Efficacy (units Lm/W)
   - Colour Rendering Index (CRI)
   - Correlated Colour Temperature (CCT) (units = K)
   - Cost of fixture
3. Design principles outlined in the standard applicable to the area being evaluated were reviewed.
4. Calculations of assessments were performed with the aid of a simulation software in order to determine the number of fixtures required. The simulation was also used to aid in the design and to verify that the design met the recommended standard. The simulation software used was DIALux, this software allows the user to design, calculate and visualize light professionally (DIAL GmbH, 2017). DIALux is used as a planning tool by over 680,000 lighting designers worldwide (DIAL GmbH, 2017).
5. A financial assessment was performed in order to determine which design would be the most cost effective solution. The financial assessment took into consideration all cost in the implementation and running of the design. The financial assessment gave an indication of the savings attained by choosing one design over another.

4. Financial Assessment

The power demand (KW) for each design considered was calculated using the following equation:

Power Demand (KW)
= (Number of lamps ×Power per lamp)/1000   (7)

The energy consumption and energy cost for each design was calculated as follows:

Energy consumption per year
= Power Demand × operating hours per year   (8)

Energy cost per year
= Energy consumption per year × Energy cost per kWh   (9)

The power demand, energy consumption and maintenance cost of each design was compared and the differences were found. These differences were used to calculate the yearly savings attained by choosing the design with the lowest energy consumption. The yearly savings attained by choosing one project (project one) over another (project two) was calculated as follows:

Total Yearly Maintenance Cost
= average maintenance cost per fixture × number of fixtures   (10)

Total yearly running cost
= Energy Cost Per Year + Total Yearly Maintenance Cost   (11)

Yearly savings
= running cost of project two-running cost of project one   (12)

The total cost of implementing a design was calculated as follows:

Total installation cost
= (number of fixtures ×installation cost for fixture)
  + (number of poles × installation cost per pole   (13)

Total purchase cost
= (number of fixtures × Cost of fixture)
  + (number of poles × Cost of pole)   (14)

Capital Cost = Total installation cost + Total purchase   (15)

The decision of choosing one project over another can result in savings. A cash flow analysis is performed to determine the savings after a period of years. The initial and yearly savings would be considered as the cash inflows. Such an analysis is shown below:

Initial Savings
= Capital Cost of project two - Capital Cost of project one   (16)

Total Savings
= Initial Savings + (yearly savings × amount of years)   (17)

The simple cash flow analysis above does not take into consideration the discount rate. A discounted cash flow analysis utilises the discount rate in order to determine the present value of future cash flows. The sum of the present values of future cash inflows, plus the initial savings would give the total discounted cash inflow. This analysis was performed with the assumption that the energy cost remains constant. The total discounted savings can be found as follows:

$$Total\ Savings_{(discounted)} = C_0 + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} \qquad (18)$$

where, C_t = cash inflow during period t (yearly savings)
  C_0 = total initial cash inflow (initial savings)
  r = Discount rate
  t = Time period (year after initial investment)
  T = Total time period (amount of years)

5. Results

The illuminance measurements taken at parking lots were used to calculate the average illuminance and uniformity ratio. Similar measurements were taken for walkways, roadways and cricket fields, respectively. Tables 7-10 compare the audit results obtained to the recommended standard.

Table 7. Results for Parking Lots

Parking Lot	E_{avg} (Lux)	E_{vmin} (Lux)	E_{vmin} (Lux)	E_{max}/E_{min}
IES RP-20-14 (Lighting for Parking Facilities)	*5*	*2.5*	*2.5*	*15*
Heart Ease	6.9	1.8 Facing (north)	1.3 Facing (south)	38.7
SPEC	6.8	0.4 Facing (east)	0.04 Facing (west)	32.8
Dudley Huggins Car Park	3.7	0.1 Facing (east)	0.5 Facing (west)	50.5
TGR South Car Park	4.2	0.5	0.4 Facing (south)	201

Table 8. Results for Walkways

Walkway	E_{avg} (lux/fc)	E_{vmin} (facing North) (lux)	E_{vmin} (facing South) (lux)	E_{avg}/E_{min}
IES RP-8-14(Roadway Lighting)	*5*	*2*	*2*	*4*
Walkway adjacent to block 13	1.8	0.3	0.3	15.3
North Entrance	6.7	1.3	2.2	3.9
South Entrance walkway	14.8	1.3	1.5	4.1

Table 9. Results for Roadways

Road	E_{avg} = Average Illuminance (lux)	Uniformity ratio = E_{avg}/E_{min}
IES RP-8-14 (Roadway Lighting)	*12*	*4*
North Roadways	23.2	11
South Entrance Roadway	9.7	16.2
Entrance from Heart Ease Car park to SAC	12.6	15.8
SPEC Entrance Roadway	6.1	10.2

Table 10. Results for Cricket Field

	E_{avg}	E_{max}/E_{min}	CV
IES (2015) RP-6-15 Recommended lighting levels for Infield (Sports and Recreational Area Lighting)	*750*	*1.5*	*0.1*
Measured levels for Infield	352.5	1.3	0.067
IES (2015) RP-6-15 Recommended lighting levels for Outfield (Sports and Recreational Area Lighting)	*500*	*2*	*0.170*
Measured levels for Outfield	314.4	4.4	0.233

6. Discussion

6.1 Parking Lots

1) At *Heart Ease Car Park*, six 250 W HPS fixtures are presently used to illuminate the car park. The fixtures were installed with a large boom angle (angle to horizontal) in an attempt to compensate for the absence of fixtures at the centre of the car park. Installing these fixtures in such a manner (large boom angle) would not only be ineffective at illuminating the car park, it can also aid in light pollution such as sky glow, light trespass and glare (McColgan, 2007). The measured illuminance at the car park met the recommended average horizontal illuminance, however, the recommended uniformity ratio and the minimum vertical illuminance were not met. The uniformity was significantly higher than the recommended value. This suggests that there were large differences in illuminance levels throughout the car park.

2) At *SPEC Car Park*, one 400 W metal halide lamp is used to illuminate the car park. This single fixture cannot properly distribute light evenly throughout the entire carpark, hence the uniformity ratio and the minimum vertical illuminance did not meet the recommended standard. The average horizontal illuminance was the only parameter that met the recommended level.

3) At *Dudley Huggins Car Park,* three 250 W mercury vapour fixtures and a 250 W high pressure sodium fixture were used to illuminate the car park. None of the fixtures at the car park were operational at the time. The entire area was divided into a grid and illuminance measurements were taken. Due to the absence of working luminaires at the car park, none of the recommended lighting levels were met.

4) At *TGR South Car Park* two 250 W high pressure sodium fixtures were used to illuminate the car park. One of the fixtures was not working at the time of the evaluation. The area was divided into a grid and illuminance measurements were taken. None of the recommended standards were met since this one fixture is unable to illuminate the entire car park.

6.2 Walkways

There were no fixtures installed on the walkway adjacent to block thirteen. High pressure sodium lamps from the neighbouring car park and savanna would aid in partially illuminating the walkway. The lighting levels on this walkway did not meet any of the recommended standards.

Ten pole top compact florescent lamp fixtures were used to illuminate the north entrance walkway. These fixtures were mounted at an average height of one point two meters (1.2m). The illuminance levels of this walkway met with respective standards except for the minimum vertical illuminance in the northerly direction. The mounting height of the luminaires on this walkway was insufficient to provide proper vertical lighting.

A 250 W mercury vapour lamp and two 250 W high pressure sodium lamps were used to illuminate the south entrance walkway, however, only one of the high pressure sodium fixtures was working at the time of the evaluation. The lighting levels of this walkway met with the recommended average horizontal illuminance. However, it did not meet the recommended minimum vertical illuminance and the uniformity ratio.

6.3 Roadways

Six 400 W Metal Halide fixtures along with four 250 W HPS fixtures were used to illuminate the SPEC entrance roadway. None of the HPS lamps were working at the time of the evaluation. The average horizontal illuminance and uniformity ratio of the roadway did not meet the recommended standard. The roadway can be divided into two sections. Section one would be the segment of the roadway that has HPS lamps and section two would be the segment that has metal halide lamps. While analysing the data gathered from these sections separately, it showed that the average illuminance of both sections did not meet with respective standards. The recommended uniformity ratio was met for section one, however, the illuminance levels on this section was very low. Table 11 shows a summary of results of the analysis.

Table 11. Results for SPEC Entrance Roadway

Section	Average Illuminance (lux)	Uniformity ratio E_{avg}/E_{min}
Section one (HPS)	1.4	2.227
Section two (Metal Halide)	9.69	16.145

The entrance roadway adjacent to Heart Ease Car Park was illuminated via 250 W high pressure sodium lamps. The average horizontal illuminance of the roadway met with the recommended standard. However,

the uniformity ratio of the roadway was significantly higher than the recommended value. The uniformity of the light on the roadway was poor due to the spacing of the poles. The poles were not uniformly spaced along the roadway, large spaces between poles caused some areas to be poorly lit. The distance of the poles from the roadway and the overhang of the fixtures also varied. These factors would also have a significant influence on the uniformity ratio of the roadway.

The south entrance roadway was illuminated via one 250 W mercury vapour lamp and five 250 W high pressure sodium lamps. The mercury vapour fixture and two of the five high pressure sodium fixtures were not working at the time of the evaluation. There was an absence of luminaires on a large segment of the roadway. Both the average horizontal illuminance and uniformity ratio of the lighting on the roadway did not meet the recommended standard.

6.4 Cricket Field

The diameter of the cricket field was measured at 400 feet. This diameter extended beyond the boundary lines of the playing area to ensure the boundary was well illuminated. The field is being illuminated via a ten pole arrangement. Sixteen 1000 W metal halide lamps are mounted on each pole, which gives a total of 160 lamps. Twelve of these lamps were not working at the time of the evaluation. The initial evaluation was performed on the main playing area of the field, and this area is called the infield. The infield is the 756.25 m^2 area located at the centre of the field. The infield encompasses the pitch where the main activities of the game occur.

The initial evaluation of the infield showed that the uniformity ratio and the coefficient of variation met the recommended standard, however, the average horizontal illuminance did not meet the recommended standard for a class two cricket field. The outfield was then evaluated using a reduced number of sample points since it was already established that the field did not meet all the recommended standards. A grid with each subsection having an area of forty square feet was used to evaluate the outfield. Analysis of the data gathered from measurements of the outfield showed that the lighting of the outfield did not meet any of the recommended standards.

7. Recommendations and Implementation Plans

The audit highlighted areas that did not meet the recommended lighting level standards. Modifications to the existing design or a complete re-design of the lighting in these areas would be required in order for the recommended IES standards to be met. The recommended luminaire layouts were different for each area due to the shape, total area and required lighting levels. The luminaire distribution types were specific to the areas in which they were placed and the layout of these luminaires were arranged in order to meet the recommended standards. These luminaires are energy efficient, have good colour rendering and provide proper lighting.

For cost effectiveness and ease of implementation, the Division of Facilities Management suggested that the fixtures used in the designs be easily accessible in the local market. The capital costs include an estimation of the installation costs along with the total purchase cost for the designs. Table 12 provides a summary of design data and references for parking lot, walkway, roadway and the cricket field. These designs recommended would meet with the lighting level standards. For illustration purposes, Figures 2 and 3 show examples of simulated design for the SPEC Car Park and the Walkway Adjacent to Block 13, respectively. Besides, Figures 4 and 5 illustrate a 3D rendering and a sample layout of luminaires at the SPEC Cricket Field, respectively.

Table 12. Summary of Design Data and References for Parking Lot, Walkway, Roadway and Cricket Field

| 1. Parking Lot Design			
	Fixtures	Number of Fixture	Capital Cost (TTD)
Heart Ease	ATG	14	$119,558
SPEC	AL07	5	$46,985
TGR South		9	$84,573
Dudley Huggins		5	$46,985
2. Walkway Designs			
	Fixtures	Number of Fixture	Capital Cost (TTD)
Walkway adjacent to block 13	ATG AL07	7	$65,779
North Entrance	QSSI KH25	3	$30,132
South Entrance walkway	QSSI KH25	3	$30,132
3.Roadway Designs			
	Fixtures	Number of Fixture	Capital Cost (TTD)
Roadways (1000 feet)	M2RR25C M-250R2 GE Lighting	21	$204,225
4.Field Designs			
	Fixture	Number of Fixture	Capital Cost (TTD)
SPEC Cricket Field	COOPER - MHXL-T5-1500-MT	120	$543,000
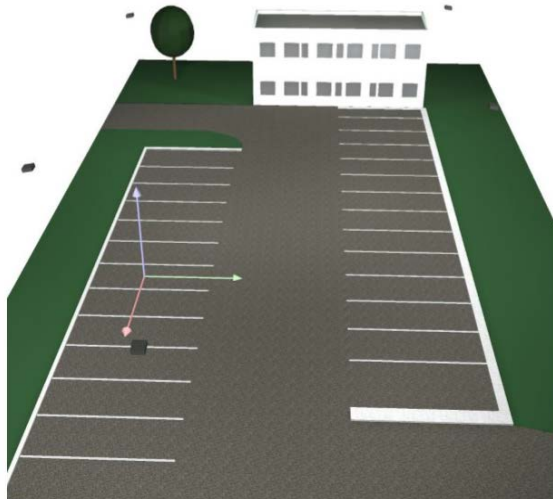
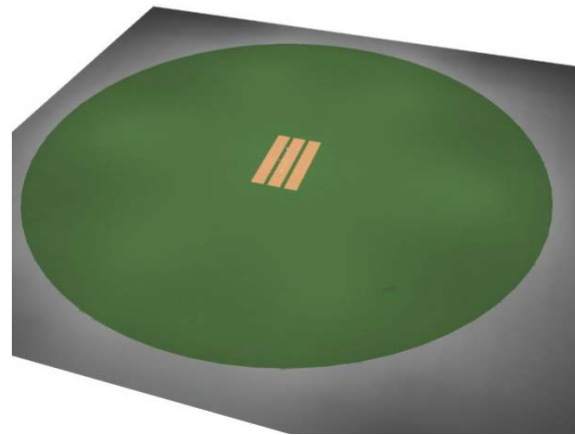**Figure 2.** 3D Rendering for the SPEC Car Park

Figure 4. 3D Rendering of the SPEC Cricket Field

Figure 3. 3D Rendering of the Walkway Adjacent to Block 13
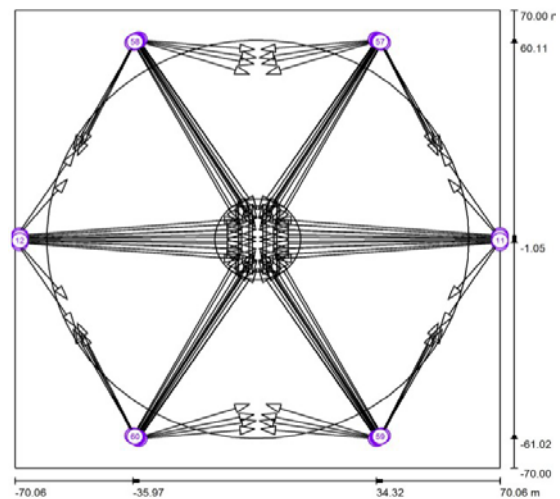

Figure 5. SPEC Cricket Field Luminaires (Coordinates List)

The simulation results of the recommended designs are summarised in Table 13 for Parking Lots and Walkways, Table 14 for Roadways and Intersections and Table 15 for the SPEC Cricket Field, respectively.

Table 13. Lighting levels of Recommended Designs for Parking Lots and Walkways

	E_{avg} (Lux)	E_{vmin} (Lux)	E_{vmin} (Lux)	E_{max}/E_{min}
1. Parking Lot				
IES) RP-20-14	*5*	*2.5*	*2.5*	*15*
Heart Ease	16	2.98 Facing (north)	2.6 Facing (south)	3.125
SPEC	21	2.8 Facing (east)	2.68 Facing (west)	1.9
Dudley Huggins	15	3.35 Facing (east)	3.08 Facing (west)	3.85
TGR South	15	2.54 Facing (north)	2.86 Facing (south)	2.273
2. Walkways				
IES RP-8-14	*5*	*2*	*2*	*4*
Walkway adjacent to block 13	14	2.29	2.29	2.31
North Entrance	19	2.34	2.31	2.7
South Entrance walkway	21	3.05	3.03	2.25

Table 14. Lighting Levels of Recommended Designs for Roadways and Intersections

	E_{avg} **(Lux)**	E_{max}/E_{min}
1. Roadways		
IES RP-8-14	*5*	*4*
Roadway	14	2.31
2. Intersections		
IES RP-8-14	*24*	*4*
Three Way Intersection	32	2.46
Four Way Intersection	72	2.77

Table 15. Lighting Levels of Recommended Designs for the SPEC Cricket Field

	E_{avg}	E_{max}/E_{min}	**CV**
IES (2015) RP-6-15 Recommended lighting levels for Infield	*750*	*1.5*	*0.1*
Design Infield Lighting levels	765	1.087	0.0242
IES-RP-6-15 Recommended lighting levels for Outfield	*500*	*2*	*0.17*
Design Outfield Lighting levels	603	1.8	0.142

8. Conclusion

The areas that were audited were identified by a survey. Results of the evaluated areas confirmed that 50% of the car parks, 66.67% of the walkways and 50% of the roadways met the recommended average horizontal illuminance defined by the IES standards. The maximum uniformity ratios of these areas were significantly higher than the recommended values and the minimum vertical illuminances were lower than the recommended values defined by the IES standards. Therefore, none of these areas met all the recommended lighting levels.

Some of the fixtures at the areas being audited were not working at the time of the evaluation, hence the lighting levels in these areas could not have met the standards. Maintenance of these fixtures should have been performed prior to the audit in order to accurately determine if the installed lighting could have met the recommended standards.

One of the major limitations in performing the audit was time. Constant rescheduling of measurements were required due to rainy weather which delayed the completion of the audit. Access to the standards reviewed was also limited. These standards were only accessible through the TTBS (Trinidad and Tobago Bureau of standards) library, therefore multiple visits had to be made in order to acquire the required information.

After the audit was conducted recommendations were made in order to improve the lighting in the areas evaluated. Recommendations for retrofit designs that would reuse the installed fixtures were not possible since specifications of the installed fixtures were not available. Recommendations were made for the installation of new fixtures that can be purchased locally. Since there were no available specifications of the existing fixtures new designs were required for 100% of the areas audited.

Acquiring quotes on fixtures that can be purchased locally proved to be a difficult task. Therefore, the designs were done using fixtures that quotes were provided for. This limited the choices of fixtures for the recommended designs. The estimated yearly maintenance cost of a fixture was $200. This cost had a significant impact on the designs recommended. The estimated capital cost was $543,000 for the recommended design for the cricket field, $298,101 for the car parks and $126,043 for the walkways. The total cost for implementing all the proposed designs was $967,144. The simulated results showed that all the recommended designs met the recommended lighting levels detailed in the applicable standards.

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