TECHNOECONOMIC ANALYSIS OF LED LIGHTING AS A SOLUTION FOR OUTDOOR STADIUM LIGHTING IN SRI LANKA

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Declaration of the Candidate & Supervisor

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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Abstract

This study explores the possibility of adopting LED lighting for professional sports lighting projects over the conventional technology. LED lighting has the advantage of lower power consumption and longer lifetime, however being a new technology LED luminaires are very expensive than conventional luminaires. Therefore in some cases it is debatable whether LED lighting is a feasible solution. Sports lighting is an area in lighting where there are very particular requirement in illumination level, uniformity, glare and colour rendering. Therefore LED luminaires specialized for sports lighting are very limited in the market. In this study, LED and conventional lighting designs are done for various sports applications and the two systems are compared. Economic analysis is done in terms of simple payback and IRR to check whether LED lighting is feasible for sports lighting in current scenario. Also various factors affecting to the feasibility of LED lighting for sports lighting is identified and sensitivity analysis is done to identify under which conditions LED lighting become advantageous over conventional lighting technology for sports lighting. In addition qualitative analysis is also done of sports luminaires of both LED and metal halide technology.

Keywords: LED lighting, stadium lighting, simple payback, IRR, sensitivity analysis

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LIST OF ABBREVIATIONS

Abbreviation	**Description**
AC	Alternative Current
CRI	Colour Rendering Index
DC	Direct Current
FIFA	Federation Internationale De Football Association
fps	Frames per second
IRR	Internal Rate of Return
LED	Light Emitting Diode
LKR	Sri Lankan Rupee
MH	Metal Halide
USM	Ultra Slow Motion

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Chapter 1

INTRODUCTION

1.1 Background

LED (Light Emitting Diode) is the newest technology introduced as a light source and today it is used in almost all the lighting applications as an energy efficient and long lasting lamp source. LED sources for light sources is still a developing technology and has not reached maturity and therefore the performance characteristics of the LED products are improving continuously. LED luminaires are now more energy efficient than most of the lamp sources such as incandescent, halogen and fluorescent therefore LED products have been now developed for applications where these technologies have been used earlier. In addition to reduction of energy consumption, LEDs also has an additional advantage of better lifetime. LED luminaires have very long lifetimes which is generally at least two or three times of a conventional technology lamp. Due to these advantages of LED light sources, LED luminaires are commonly used in indoor lighting applications where conventional technologies like fluorescent and halogen were used.

Sports lighting is a very special lighting application where several lighting criteria like illumination level, uniformity, glare ratings and colour rendering index is very critical. Different sports require different lux levels according to the speed and the nature of the sport. Also depending on the different sports venues, special lighting arrangements should be implemented so that the lighting will not interfere to the performance of the players and the viewing experience of the spectators. If the sports event is televised then there are special requirement to achieve a good video quality. The higher lux levels are required and also the colour rendering index of the lamps source has to be very high. Although technologies like halogen and sodium vapour were used for sports lighting applications, metal halide has become the widely used technology because it has a very high lumen efficacy, (which results in less energy consumption) and very good colour rendering index.

1.2 Motivation

It was noted that at the time of this project was initiated, although many LED luminaires are utilized in outdoor lighting applications like road lighting and area lighting, the LED lighting is not been used in most of the sports lighting applications. There are several reasons for the slow development of LED luminaires for sports lighting

In sports lighting generally the area to be illuminated is quite large. Therefore the required amount of light is substantially large. Therefore in order to reduce number of luminaires (due to practical reasons) generally high wattage luminaires are utilized. Generally lumen output of single luminaire should be at least in the range of 100000-150000lm. When LED luminaires of this light output have to be developed the heat generated form the luminaire is very high. In LED fixtures, the heat has to conducted out as fast as possible, to ensure proper operation and long lifetime of the LED chip. Therefore in these high output luminaires heat management is a big technological challenge the LED luminaire manufacturers have to overcome.

On the other hand the conventional metal halide technology that is used in sports applications, metal halide is a very energy efficient technology. Metal halide lamps generally have more than 100lm/ W, and at the luminaire level efficacy is generally more than 75lm/W (considering conventional luminaires developed for sports lighting applications). Further the lifetime of the metal halide lamps is also around 20000 hours. Therefore the LED luminaires have to have lumen efficacy and lifetime more than that of these metal halide luminaires. Since at the current pricing levels LED luminaires are three four times expensive than conventional luminaires, LED luminaires have to have significantly high lumen efficacy and life time if they are to economical solution over the conventional luminaires.

However today several manufacturers have introduced commercial LED luminaires for sports applications. Therefore the objective of this study was to compare these LED luminaires with conventional luminaire and see whether they are economical at the current pricing and energy performance levels. If this was not found economical, it was intended to find out under which pricing levels and energy performance levels will the LED products will be economical for sports lighting applications. Since the LED is still a developing technology, it is expected that the energy efficiency of the LEDs will increase and the pricing levels of LEDs will decrease over the time.

1.3 Literature Review of Present Work

The research work done to compare LED and metal halide lighting is very limited due to the novelty of LEDs in sports lighting applications.

Boxler [1] has conducted a study to evaluate the ability of an LED lighting system to achieve equivalent or better lighting performance when compared to the MH (Metal Halide) system. Pole heights were held constant between the MH and LED designs to enable offsite spill and glare light comparisons between the two systems. It is important to note that this study has been done in 2011 and the researcher has designed a sport lighting luminaire with Cree® XLamp® XP-G LED which was deemed to have the highest efficacy when run in high current applications at the time of the study. Two identical Class III football fields (requirement of average horizontal illumination is 30 footcandles) have been illuminated with LED luminaire (developed by the researcher) and other field has been illuminated by latest generation of Musco Metal Halide fixtures available at the time of the study.

The results that have been achieved are as follows.

Table 1.1: Comparison of results of LED and metal halide systems

	Average horizontal illumination	**Maximum /Minimum ratio**	**Field Efficacy**	**Maximum Glare Candela at 100 feet**
LED	42 footcandles	1.28:1	30.9 Lumens/Watt	82,510 cd
MH	36 footcandles	2.67:1	43.2 Lumens/Watt	1,612 cd

From the above results we can see that the LED have achieved the required illumination level. However the energy efficiency of the LED system has been lower than that of the Metal halide system. In this study the energy efficiency of the system has been measured by a criteria called field efficacy which is defined by the below equation.

$$Field\ Efficacy\ \left(\frac{lm}{W}\right)$$
$$= \frac{Field\ area\ (sq.ft)x\ Average\ Maintained\ Footcandle\ Level\ (footcandle}{Total\ Power\ (Watts)}$$

Hence according to the results in the table 1 we see that the LED system is less energy efficient than the metal halide system. Boxler [1] have stated that with the level of technology used for this demonstration, LED lighting is not competitive with modern MH systems in terms of field efficacy. The primary disadvantage of using LEDs in this situation is the need to drive the LED at high currents in order to strike a balance between component/fixture count and total lumen output. Characterization of the LED at high currents shows reductions in luminous efficacy of approximately 35% when operated near maximum current ratings.

From the results of Table 1.1 we can observe that LED system has better uniformity ratios than the metal halide. Boxler [1] have stated LED field shows a significant improvement in beam uniformity on the field. Visual observation of the field also shows that the LED field uniformity is noticeably improved when compared to the MH field. Qualitative evaluations of the field by several observers indicated a preference for the LED field based on the uniformity. These conclusions are subjective judgments at this point and further study would be needed to quantify the uniformity advantage. However, based on initial experience, this appears to be an advantage that LED sports lighting systems might offer.

The study also comprised of comparing the offsite glare created by both systems. According to Boxler [1], LED field presents a substantial reduction in offsite glare as quantified by the candela reaching the observer. This is primarily due to increased optical control available from the individual optics over each source and the ability to use the exterior housing to help shield glare without substantially affecting overall luminaire output.

At the time of this LEDs that were available for sports application were not able to be more energy efficient than metal halide. However the study showed that LEDs have other advantages over metal halide. Author have stated that The LED system developed for this study has demonstrated that LEDs can be successfully applied in a sports lighting application. While the system does incur substantial cost penalties over an existing Metal Halide system, there were significant improvements to the overall lighting quality on the sports field. Specifically, there was an observed improvement in uniformity of the playing surface and a large reduction in offsite spill light and glare. The improvement in uniformity may allow for improved playability and the LED system can provide better control of wasted spill light, glare, and sky glow which can be advantageous in installations in close proximity to residential areas. With expected improvements in LED efficacy combined with the advantages afforded by improved beam uniformity and light control, solid state lighting should provide an opportunity to improve sport lighting applications in the future.

Lee et al. [2] have conducted a study in 2015 where they have designed an LED lighting system for a indoor badminton court complex.

They have designed a special LED luminaire for this purpose. According to the authors, the lighting mechanism of stadium lighting uses a method of three surface radiation. Light emits from lighting modules to volume scattering diffusers, which has a one-shot transmittance higher than 70%, so that a smaller original light-emitting area is extended to become three larger light-emitting areas. The function of the volume scattering diffuser is helpful to result in a comfortable and soft lighting effect and restrain the influence of glare by reducing the luminance of the LED luminaire.

This indoor stadium have previously used some highbay luminaires with different types of gas discharge bulbs. There have not been a proper layout and these conventional lighting fixtures were not professional sports lighting luminaires., hence there has been issues with regards to direct glare and non uniformities. However according to Lee et al. the average illuminance on the ground of whole area of badminton court is enhanced from 150 lx to 430 lx at the same power consumption of 10000 W in practical measurement. Under the similar condition of electric power consumption, compared with original lighting condition by using traditional lamps, the average illuminance on the ground is enhanced approximate 300%. Besides, the switch-on speed of luminaire is greatly reduced from 5 – 10 minutes to 1 second. The users can arbitrarily select a court, which they need, and enjoy their sport in the stadium with comfortable lighting condition.

Although this study has not been done in comparing two professional sport lighting systems in LED ad metal halide, this study also indicates the possibility of gaining energy saving and better uniformity by using LED luminaires for sports applications. Also Lee et al. [2] have mentioned another advantage of LED lighting sports application which is the reduction of switch on time. Normally metal halide lamps take at least 5 -10 minutes to reach to its maximum output. However LEDs have instant switching on feature. This is very advantageous at a time of restoration of power after a system failure where LEDs will instantly illuminate when the power is restored, which will minimize the interruption to the sports event.

With regards to comparison of LED and conventional technology, Tähkämö, Räsänen and Halonen [3]have conducted a study to compare the life cycle cost high pressure sodium and LED in street lighting. In this study life cycle cost analysis was conducted for the high-pressure sodium and light-emitting diode luminaires including the investment costs, operating costs and residual value over 30-year time frame. The investment costs included the purchase prices of all parts, freight and installation costs. The operating costs accounted for the energy and maintenance costs, and the residual value was calculated using the 25 % estimate of the initial purchase price. The approach of the calculation considered only the luminaires to be installed; the scope of the study excluded the previous installations, which may contain any light source technology or be inexistent. They have done the design for one base case where according to the authors the initial investment of the LED luminaire was approximately 2.3 times greater than those of the HPS luminaire. The energy costs of the LED luminaire were 27 % lower than those of the HPS luminaire, but the maintenance costs of the LED luminaire were 17 times greater compared to those of the HPS luminaire. As a sensitivity analysis they have considered six scenarios where the electricity price, spot replacements, LED luminaire price, life of the HPS lamp and the LED luminaire and the modularity of the LED luminaire was varied. The sensitivity analysis indicated that in order for the LED luminaire to become more economical, i.e. having lower LCCs than the HPS luminaire, the scenarios need to occur simultaneously.

Tähkämö, Räsänen and Halonen [3]have concluded that LED luminaires are an merging technology with unrealized efficiency potential. This potential may be realized as the increased number of LED luminaire suppliers enhances competition, which drives the purchase price down in the LED segment and thus reduces the investment cost. Furthermore, the maintenance costs of LED luminaires may be reduced as product quality improves due to increased use of automation in system integration in luminaire manufacturing.

The studies reviewed above suggest that there may or may not be energy savings from LEDs in sports lighting over metal halide or any other conventional technology depending on the performance level of the LED product used. Also there are some additional advantages of LED lighting in sports applications other than the energy saving such as improved uniformities and reduction of spill light. Also most of the researchers expect that with advancement of LED lighting technology, LED lighting will become a feasible option for sports lighting.

Chapter 2

PROBLEM IDENTIFICATION AND PRELIMINARY WORK

2.1 Identification of the Problem

As it was discussed in the previous chapter, LED lighting is not very common in sports lighting applications and the situation is same in Sri Lanka. In Sri Lanka there are several major stadiums that have been lighted up according to all relevant international standards. Most of them are cricket grounds; however there are some grounds for football, athletics and rugby as well. In none of these grounds LED is considered as an option for flood lighting even at the evaluation stage due to the very high additional investment that is involved with LED lighting.

However as it was discussed in the literature review LED lighting can bring several benefits including the possible energy savings. However the feasibility of implementing such LED lighting system to a project in Sri Lanka has not yet been explored by anybody since it is assumed that there won't be any payback for the additional initial investment involved in the project.

Therefore this study aims to analyze the economic feasibility of LED lighting to a sports lighting project in Sri Lanka by designing and comparing LED and metal halide lighting systems to a real world outdoor stadium in Sri Lanka. It is important to note that in this study we look at new stadium lighting projects where the stadium currently do not have flood lighting since in this scenario an expensive technology will be more feasible rather than in a project where the conventional flood lights are already installed.

Also the luminaire used for the designs and comparisons will be real world products which carry the latest development in the LED technology and the actual pricing is also considered. Hence the data considered for this study will reflect the actual scenario at the time of the research.

If the project is found not feasible at the current technology level and pricing level, it is required to find out under which conditions in the scenario that LED lighting would be feasible. This shall be done with a sensitivity analysis.

2.2 Preliminary Work

As preliminary work for the study a survey was conducted on the commercially available sports lighting fixtures. Since sports lighting applications are very critical manufacturers usually have specialized luminaires for sports lighting.

One important feature required is the excellent beam control. In outdoor lighting projects sometimes that light beam have to travel at least 10m since the area to be lit up is quite large. Therefore these luminaires should have very narrow beam angles. Also the lumen output of the luminaire should be very high, (in the range of 70,000lm-100,000lm) since the area to be lit up is very high and the illuminance levels required is also very high (usually more than 200 lux). If large number of small output luminaire to be used, there will be a problem in designing masts or any other mounting arrangement. Also since the luminaire is used with high power lamps the luminaire should be designed to handle high currents.

Since these luminaire is installed in an outdoor location ingress protection of at least IP65 is required and also the vandal resistance grade of at least IK05 will be required. In cases where the sports events are telecasted over the television, The colour rendering index of the lamp should be at least 90. Out of all the conventional lighting technologies that are available, metal halide is the technology that can easily comply to these requirements. Therefore most of the luminaires that are specialized for sports lighting are metal halide ones.

The summary of the findings of the survey are as tabulated in the Table 2.1.

Table 2.1 :Summary of the sports lighting luminaires in the market

Conventional- Metal Halide			**LED**		
Item	**Lumen output of luminaire**	**Luminaire Lm/W**	**Item**	**Lumen output of luminaire**	**Luminaire Lm/W**
Brand A 2kW	164000	78.1	Brand A product 1	135000- CRI 90 152000- CRI 80 194000- CRI 70	95.8
			Brand A product 2	65000	118.18
Brand B	Data not available	Data not available	Brand B	44605	94.9
Brand C 2 kW	150500	75.2	Brand C	Data not available	Data not available

For the calculations done for this study Brand A was selected because all the required data (for the design) was available for only Brand A.

Chapter 3

ESTIMATION OF COST OF CONVENTIONAL & LED FLOOD LIGHTING SYSTEM

For the estimation of flood lighting in both technologies two stadiums in Sri Lanka were selected. In order to generalize the results we obtain, two grounds were selected. One ground is a football ground and the other ground is a cricket ground. Since the sports played in these two grounds are different, the area and the shape of the ground to lit up is different. Also the required lux levels are also quite different. Since these are completely different lighting requirements the results we observe from these two cases can be taken as a generalized outcome. We have used 3 test cases as mentioned below in Table 3.1 for the study.

Table 3.1 : Summary of the test cases

Test Case	**Sports played in the stadium**	**Illumination levels considered**
Test Case 1	Football	National level requirement for telecasted events 2500 Lux
Test Case 2	Football	National level requirement for non telecasted events 750 Lux
Test Case 3	Cricket	International level requirement for HDTV coverage Pitch : 3000 Lux Inner field : 2500 Lux Outer Field : 1000 Lux

For all three cases, we will be calculating the energy savings obtained by LED lighting to get a general figure of the energy saving that can be obtained by LED luminaires (currently available) in sports lighting.

3.1 Cost Estimations for the Test Case 1 for Conventional (Metal Halide) Lighting System

As described in the table 3.1 for the test case 1, a football stadium was selected and the horizontal illuminance level requirement considered was 2500 lux which is the requirement for televised national level football game as per FIFA (Federation Internationale De Football Association) standards.

As the first step of cost estimation the lighting design was carried out to calculate the number of luminaires required to achieve the above mentioned lighting levels.

The Calculux Area software was used for lighting calculations since the software was easily accessible and it is a software dedicated to outdoor floodlighting designs. Appendix A contains a brief description of the methodology followed in doing a lighting design with Calculux Area software.

The lighting design was carried out with 2kW metal halide luminaires of Brand A in 4 mast configuration and maintenance factor of 0.8. With 324 luminaires (81 luminaires per mast) the required lux level was achieved with recommended levels of uniformities as illustrated in the table 3.2.

Table 3.2: Results achieved in lighting design for test case 1 (Metal Halide)

Design Criteria		**Values Achieved**	**Requirement**
Horizontal	Average Illuminance	2539	2500
	U2(min/average)	0.82	0.8
	U1(min/max)	0.72	0.6

The results achieved are indicated in following figure 3.1 as well.

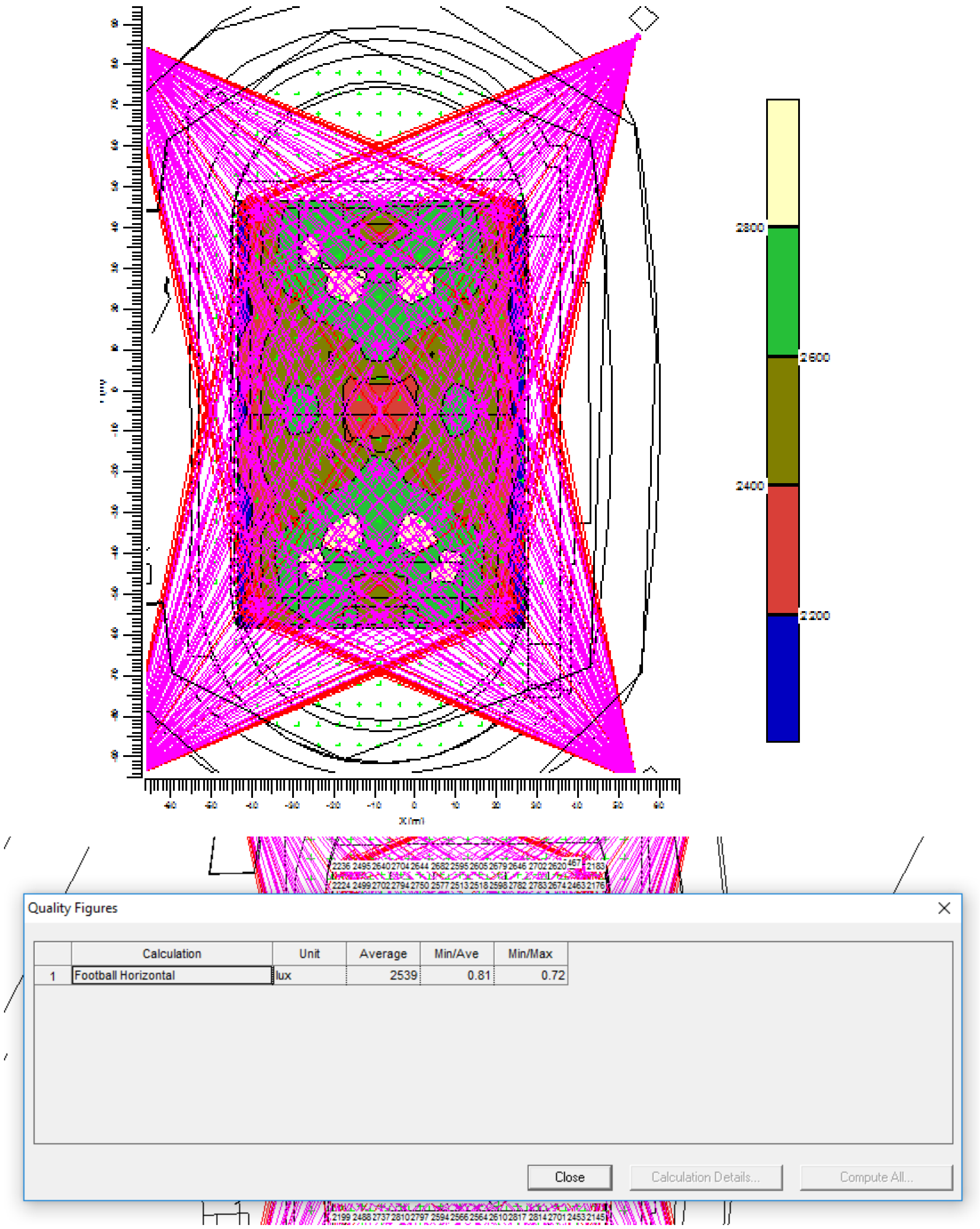

Figure 3.1 : Results achieved in lighting design for test case 1 (metal halide)

Please refer Appendix B for complete results of lighting design.

After calculating the number of luminaires , the power distribution system was designed and the associated cost was determined. Please refer Appendix C for single line diagram and Appendix D for detailed cost estimation of power distribution system.

Finally the cost of the mast and foundation was also determined form the data supplied by a mast manufacturer. The final cost of the test case 1 with metal halide luminaires is illustrated in table 3.3

Table 3.3 : Results achieved in cost estimation of test case 1 (Metal Halide)

Scope of Work	**Estimate (in Rs millions)**
Supply and installation of lighting equipment	70
Supply and installation of power distribution	65
Supply and erection of masts	72
Testing & commissioning	1
Total	**208**

3.2 Cost Estimations for the Test Case 1 for LED Lighting system

As the first step of cost estimation the lighting design was carried out to calculate the number of LED luminaires required to achieve the above mentioned lighting levels for test case 1.

The lighting design was carried out with 1.4kW Brand A luminaire (CRI70 version since Football standard requires a minimum CRI of 65) LED luminaires in 4 mast configuration and maintenance factor of 0.8. With 380luminaires (95 luminaires per mast) the required lux level was achieved with recommended levels of uniformities as illustrated in the table 3.4.

Table 3.4: Results achieved in lighting design for test case 1 (LED)

Design Criteria		**Achieved Values**	**Requirement**
Horizontal	Average Illuminance	2638	2500
	U2(min/average)	0.82	0.8
	U1(min/max)	0.61	0.6

The results achieved are indicated in following figure 3.2 as well.

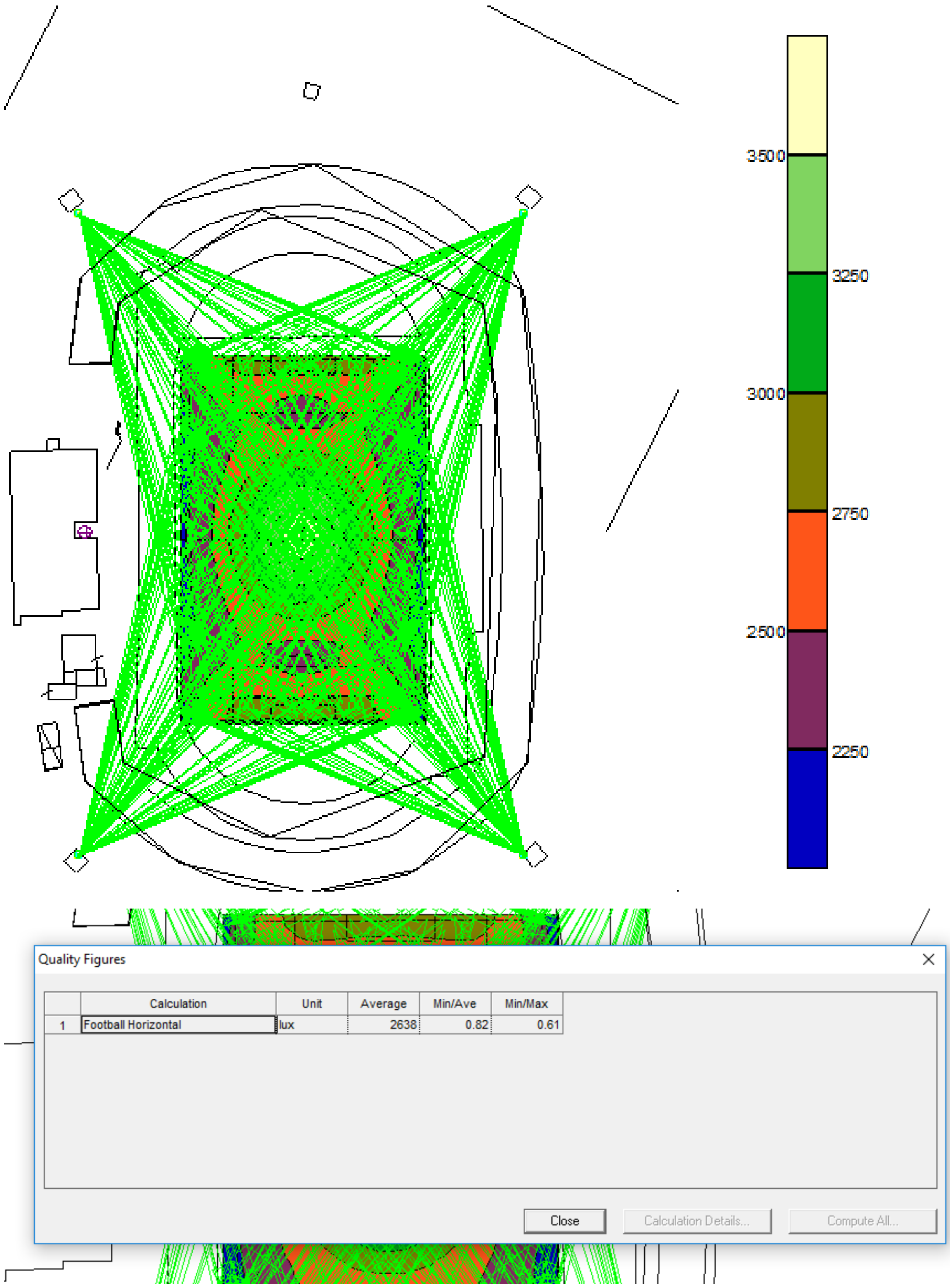

Figure 3.2 : Results achieved in lighting design for test case 1 (LED)

Please refer Appendix E for complete results of lighting design.

After calculating the number of luminaires , the power distribution system was designed and the associated cost was determined. Please refer Appendix F for single line diagram and Appendix G for detailed cost estimation of power distribution system.

Finally the cost of the mast and foundation was also determined form the data supplied by a mast manufacturer. The final cost of the test case 1 with metal halide luminaires is illustrated in table 3.5.

Table 3.5 : Results achieved in cost estimation of test case 1 (LED)

Scope of Work	**Estimate (in Rs millions)**
Supply and installation of lighting equipment	289
Supply and installation of power distribution	55
Supply and erection of masts	90
Testing & commissioning	1
Total	**435**

3.3 Comparison of Two Lighting Technology for Test Case 1

The comparison of energy consumption and initial investment of the LED and metal halide systems can be summarized in below table 3.6.

Table 3.6 : Comparison of results for the test case1 in LED and metal halide lighting systems

	Metal Halide	**LED**
Power consumption (kW)	680	535
Initial Investment (LKR in millions)	208	435

As per the above table LED system reduce the energy consumption by 21% and the initial cost of LED system is 2.09 times of the initial cost of the metal halide system.

3.4 Estimation of Energy Consumption of the Test Case 2 for Conventional (Metal Halide) Lighting System

As described in the table 3.1 for the test case 2, a football stadium was selected and the average horizontal illuminance level considered was 750 lux which is the requirement for national level Football events which are not telecasted on television as per FIFA standards.

The lighting design was carried out with 2kW brand A metal halide luminaires in 4 mast configuration and maintenance factor of 0.8. With 116 luminaires (29 luminaires per mast) the required lux level was achieved with recommended levels of uniformities as illustrated in the table 3.7

Table 3.7 : Results achieved in lighting design for test case 1 (Metal Halide)

Design Criteria		**Achieved Values**	**Requirement**
Horizontal	Average Illuminance	771	750
	U2(min/average)	0.73	0.7

The results achieved are indicated in following figure 3.3 as well.

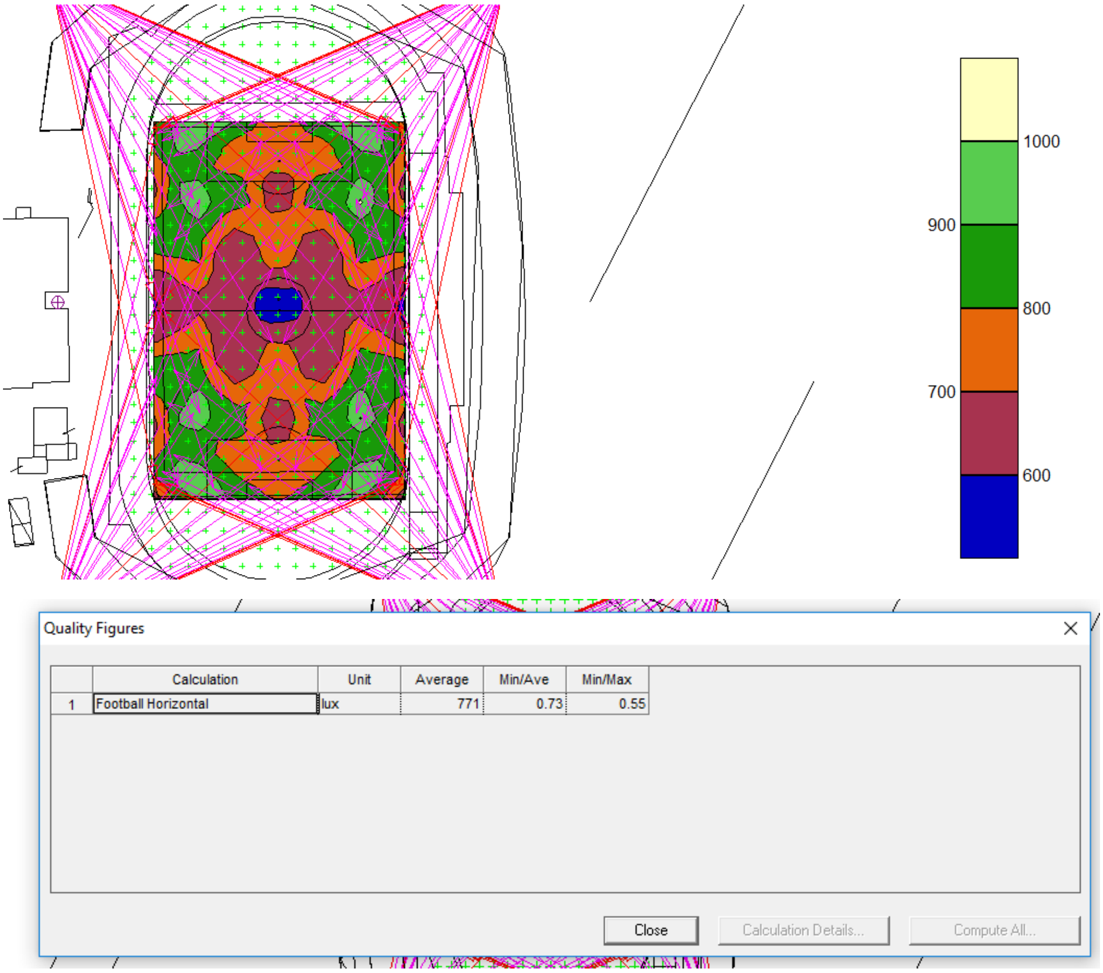

Figure 3.3 : Results achieved in lighting design for test case 2 (Metal Halide)

Please refer Appendix H for complete results of lighting design.

3.5 Estimation of Energy Consumption of the Test Case 2 for LED Lighting System

The lighting design was carried out with 1.4kW Brand A (CRI80 version) LED luminaires in 4 mast configuration and maintenance factor of 0.8. With 140 luminaires (35 luminaires per mast) the required lux level was achieved with recommended levels of uniformities as illustrated in the table 3.8.

Table 3.8: Results achieved in lighting design for test case 2 (LED)

Design Criteria		**Achieved**	**Requirement**
Horizontal	Average Illuminance	790	750
	U2(min/average)	0.87	0.7

The results achieved are indicated in following figure 3.4 as well.

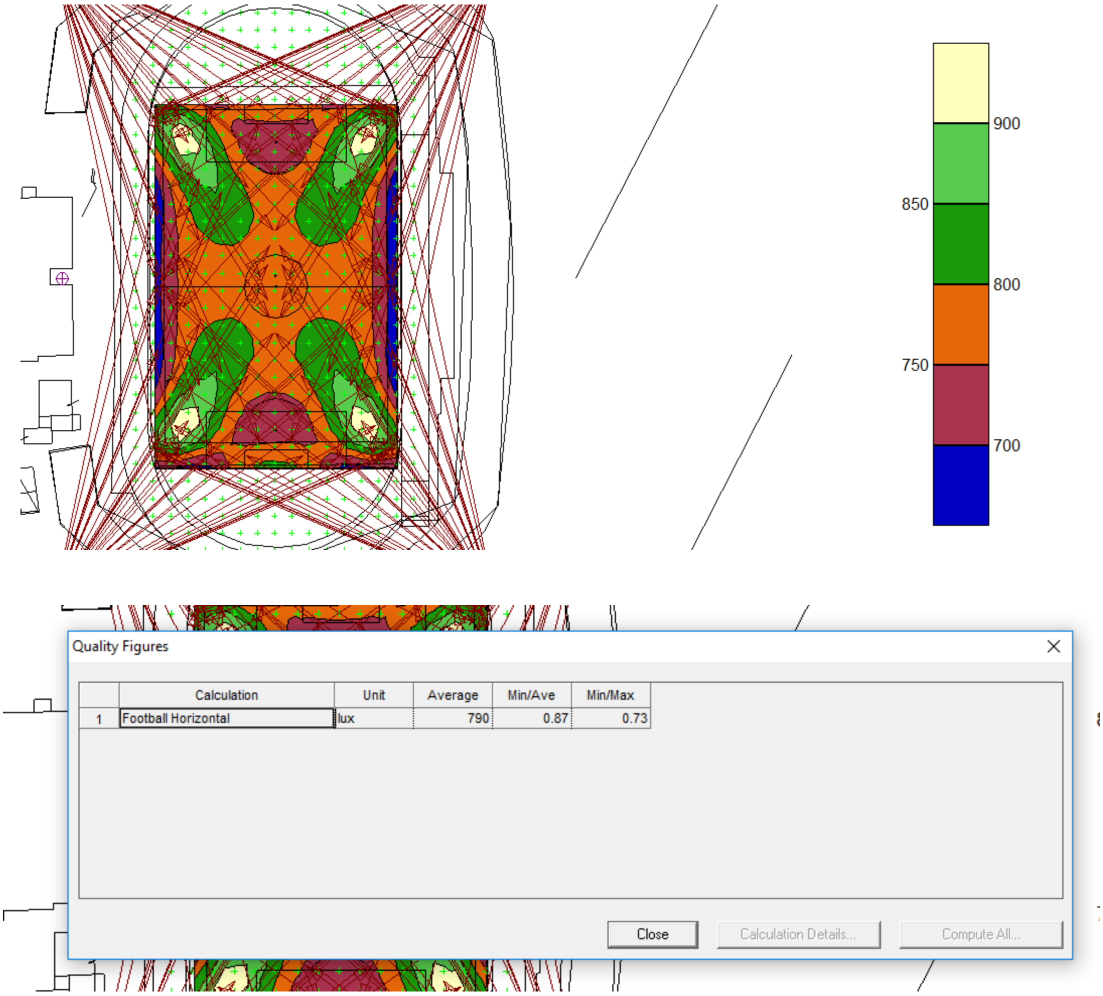

Figure 3.4 : Results achieved in lighting design for test case 1 (LED)

Please refer Appendix I for complete results of lighting design.

3.6 Comparison of Two Lighting Technology for Test Case 2

The comparison of energy consumption of the LED and metal halide systems can be summarized in below table 3.9.

Table 3.9: Comparison of energy consumption for the test case2 in LED and metal halide lighting systems

	Metal Halide	**LED**
No of Luminaires	116	140
Power consumption (kW)	243.6	197.4

As per the above table LED system reduce the energy consumption by 19% .

3.7 Estimation of Energy Consumption of the Test Case 3 for Conventional (Metal Halide) Lighting System

As described in the table 3.1 for the test case 3, a cricket stadium was selected and the average horizontal illuminance level requirement considered was 3000 lux in pitch, 2500 lux in inner field and 2000 lux in outer field which is the requirement for international televised cricket events which are as per ICC standards..

The lighting design was carried out with 2kW brand A metal halide luminaires in 4 mast configuration and maintenance factor of 0.85. With 624 luminaires (156 luminaires per mast) the required lux level was achieved with recommended levels of uniformities as illustrated in the table 3.10.

Table 3.10: Results achieved in lighting design for test case 3 (Metal Halide)

Design Criteria		**Achieved Values**	**Requirement**
Horizontal-Pitch	Average Illuminance	3250	3000
	U2(min/average)	0.91	0.7
	U1(min/max)	0.84	0.6
Horizontal-Inner Field	Average Illuminance	2674	2500
	U2(min/average)	0.9	0.6
	U1(min/max)	0.73	0.5
Horizontal-Outer Field	Average Illuminance	2004	2000
	U2(min/average)	0.68	0.5
	U1(min/max)	0.46	0.4

The results achieved are indicated in following figure 3.5 as well.

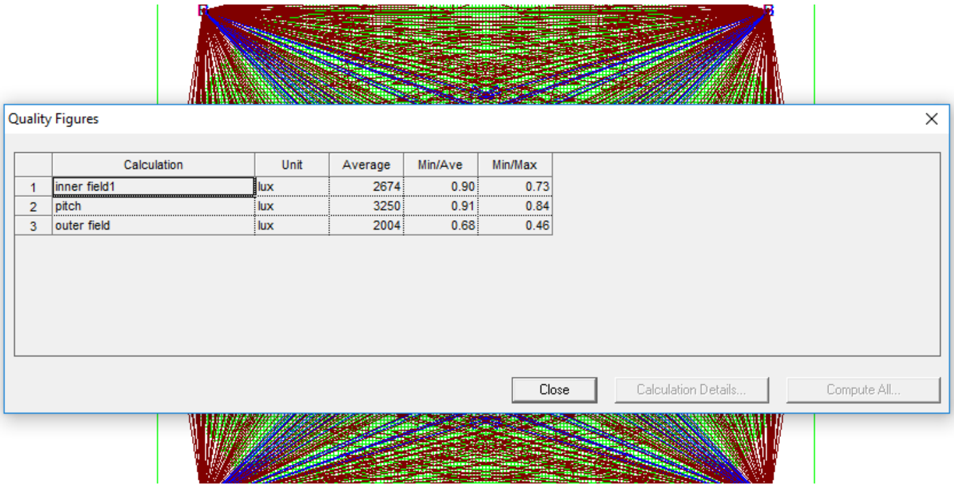

Figure 3.5: Results achieved in lighting design for test case 3 (Metal Halide)

Please refer Appendix J for complete results of lighting design.

3.8 Estimation of Energy Consumption of the Test Case 3 for LED Lighting System

The lighting design was carried out with 1.4kW brand A (CRI90 version as ICC standard requires CRI to be more than 90) LED luminaires in 4 mast configuration and maintenance factor of 0.85. With 752 luminaires (188 luminaires per mast) the required lux level was achieved with recommended levels of uniformities as illustrated in the table 3.11.

Table 3.11: Results achieved in lighting design for test case 3 (LED)

Design Criteria		**Achieved Values**	**Requirement**
Horizontal-Pitch	Average Illuminance	3046	3000
	U2(min/average)	0.95	0.7
	U1(min/max)	0.9	0.6
Horizontal-Inner Field	Average Illuminance	2569	2500
	U2(min/average)	0.88	0.6
	U1(min/max)	0.78	0.5
Horizontal-Outer Field	Average Illuminance	2008	2000
	U2(min/average)	0.59	0.5
	U1(min/max)	0.42	0.4

The results achieved are indicated in following figure 3.6 as well.

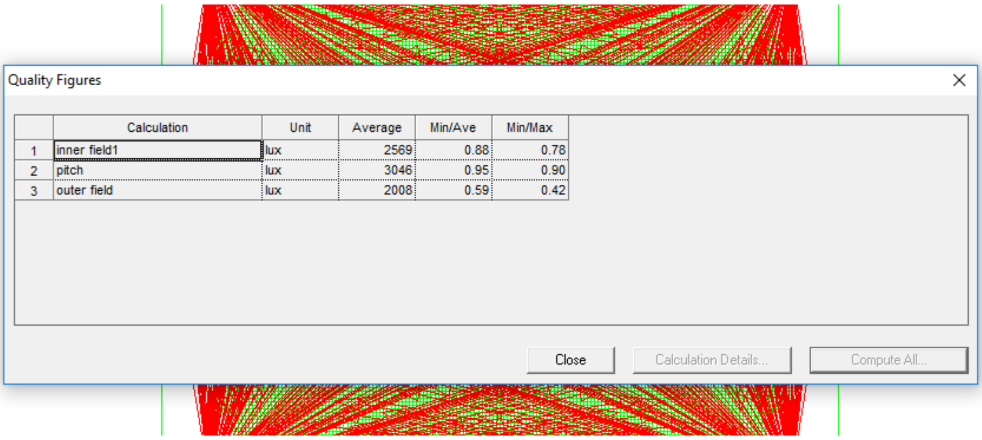

Figure 3.6 : Results achieved in lighting design for test case 3 (LED)

Please refer Appendix K for complete results of lighting design.

3.9 Comparison of Two Lighting Technology for Test Case 3

The comparison of energy consumption of the LED and metal halide systems is summarized as illustrated in below table 3.12.

Table 3.12: Comparison of energy consumption for the test case 3 in LED and metal halide lighting systems

	Metal Halide	**LED**
No of Luminaires	624	752
Power consumption (kW)	1310.4	1060.3

As per the above table LED system reduce the energy consumption by 19% .

3.10 Summarization of the Results

In the above sections we have analyzed three test cases where the required illuminance levels and area to be lit up were different from each other. The results of the calculation of the above three test cases as summarized in the table 3.13

Table 3.13: Comparison of energy consumption in LED and metal halide lighting systems

Test Case	**Energy Consumption of Metal Halide System (kW)**	**Energy Consumption of LED System (kW)**	**Energy Saving**
Test Case 1	680	535	21%
Test Case 2	243.6	197.4	19%
Test Case 3	1310.4	1060.3	19%

From the above summarized results we can come to the conclusion that irrespective of the illuminance level required and the shape of the stadium, LED lighting systems is generating an energy saving of around 20% over the metal halide lighting system. Therefore we can conclude that using test case 1 for all future calculations since it represents the results obtained in other two cases are almost the same.

Chapter 4

ECONOMIC ANALYSIS

In the previous chapter we have observed that the LED lighting system introduces an energy saving of around 20%, however we have also noted that for a new project, the cost of an LED lighting system is two times that of the cost of a metal halide system. Hence in this chapter we will carry out the analysis to determine whether the energy saving acquired by the LED is significant enough to compensate to the additional initial investment required by an LED lighting system.

4.1 Economic Analysis Methods Used

For this research we have considered two economic analysis tools. One is simple payback method and the other is the IRR (Internal Rate of Return).

Simple payback period is the time period required to recover the initial investment made. In this case we will calculate how many years will be taken to the recover the additional investment made for an LED lighting system (rather than implementing a conventional lighting system). When calculating the recovery of the investment we have considered two components, saving in energy consumption and saving in lamp replacement (since LED luminaires have a very long lifetime hence the expenditure on lamp replacement will be saved).

Next method used is the internal rate of return (IRR). IRR is the discount rate at which the net present value of all the cash flows (both positive and negative) from a project or investment becomes zero. Since all the above mentioned saving will be taking place in the future we need to convert them to a present value by applying a discount rate. IRR is the rate at which the net present value is zero which means that at any rate higher than the IRR , the project will have a positive present value which means the actual discounted saving from the project (saving in energy consumption and saving in lamp replacement) will be higher than the initial investment.

In this research we have considered implementation of a new sports lighting project and analyzing whether it is feasible to implement a LED lighting system rather than a conventional metal halide lighting system. Therefore in both these calculations the additional investment made for LED lighting system (the difference of the cost of the two systems) was considered as the initial investment which is cash outflow and the savings earned from reduction of energy consumption and reduction of lamp replacement was considered as future cash inflows.

Both of the these calculations will depend on several factors.

- Luminous efficacy of the of the LED luminaire: the product considered for lighting design has a lumen efficacy of 95.8lm/W Since the LED is still developing, more efficient luminaires will be developed in the future hence this value will increase

- Cost of the LED luminaire: Current pricing level of specialized LED sports lighting luminaires was considered for the calculation. However with the development of LED lighting technology pricing of LED luminaires are reducing gradually
- Annual duration of operation of flood lighting system: This largely depends on the stadium considered and the types of sports played in the stadium
- Energy Tariff: This largely depends on the power source used in the stadium.

4.2 Simple Pay Back Calculation

Simple payback calculation was done for test case 1 as it was considered as the generalized case as per table 3.13

The below assumptions and values were taken for simple payback calculation.

- The flood lighting system is operated 400 hours per year
- The tariff rate would be 25 LKR (Sri Lankan Rupees)/unit (since most of the stadiums are operated with diesel generators)
- The LED luminaire used for lighting design has 95.8lm/W
- Current pricing level of LED luminaires is 5500 LKR per one klm.

Under the above assumptions and values the simple payback was calculated. The detailed calculation is attached in Appendix L.

As per this calculation the simple pay back period is 12 years. The useful lifetime of the LED luminaire is 50000 hours which is theoretically more than 100 years (with 400 operating hours per year). However a payback of 12 years is generally not acceptable therefore from the simple payback analysis we can conclude that LED lighting for the sports stadium is not viable under current conditions and assumptions.

4.3 IRR Analysis

IRR calculation was done for test case 1 as it was considered as the generalized case as per table 3.13

For the IRR calculation, the below assumptions and values were taken.

- The flood lighting system is operated 400 hours per year
- The tariff rate would be 25 Rs/unit (since most of the stadiums are operated with diesel generators)
- The LED luminaire used for lighting design has 95.8lm/W
- Current pricing level of LED luminaires is 5500 LKR per one klm
- The financing method of the project was assumed as follows.
    - Debt to Equity ratio is 4:1
    - Loan is taken for five years
    - Interest rate for the loan is 11%

Under the above assumptions and values the IRR was calculated. The detailed calculation is attached in Appendix 12

The calculation results indicated a project IRR of 3% and equity IRR of 1%. Considering that any risk free investment will have a return of at least 8%-10%, for this kind of a project to be financially viable the project should at least have a IRR value higher than this risk free return rate.

Therefore from the IRR analysis we can conclude that LED lighting for the sports stadium is not viable under current conditions and assumptions.

Chapter 5

SENSITIVITY ANALYSIS

It was observed in the previous chapter that there are several factors affecting to the simple payback period and IRR. Due to different factors these values may change and as a result the payback period and IRR value will also change.

Hence a sensitivity analysis was carried out to check how the payback period and IIR value will change with the variations in the above mentioned factors. For this sensitivity analysis several scenarios were selected.

5.1 Scenarios Considered for Sensitivity Analysis

In scenario 1, the price of the luminaire was varied and the respective IRR and payback periods were calculated. . In this scenario all other values were kept at the values taken for economic analysis. It is important to note that these pricing levels discussed here are in relevant to professional sports lighting luminaires and not for general purpose LED luminaires. The price of the LED luminaires will be gradually decreasing with the advancement and maturity of LED lighting technology, therefore we can expect lower price level in the future. Also with the advancement of the LED technology luminous efficacy of the luminaire will improve. Hence in scenario one the calculation was done for various luminous efficacies so that we can see at a given pricing level, what will be the payback/IRR under different luminous efficacies.

In scenario 2, the cost of Kwh was varied and the respective IRR and payback periods were calculated. All other values were kept at values taken for economic analysis. The energy cost will depend on different power sources and hence will vary form stadium to stadium. Therefore in this scenario we can observe what will be the payback period and IRR for stadiums which have different energy costs. As in the first scenario since the luminous efficacy of the luminaires is expected to improve, the calculation was done for various luminous efficacies as well, hence we can see that in future how the LED lighting will be feasible with higher luminous efficacies.

In scenario 3, the annual operating hours was varied and the respective IRR and payback periods were calculated. All other values were kept at the values taken for economic analysis.

The operating hours will depend on different stadiums and the sports played in stadium, and hence will vary form stadium to stadium. Therefore in this scenario we can observe what will be the payback period and IRR for stadiums which have different operating durations. As in the other two scenarios since the luminous efficacy of the luminaires is expected to improve, the calculation was done for various luminous efficacies as well, hence we can see that in future how the LED lighting will be feasible with higher luminous efficacies for different stadiums with different durations of operation.

5.2 Simple Payback Calculation Sensitivity Analysis Scenario 1

As explained earlier the simple payback was calculated with the variation of pricing of LED luminaires. The results of the calculation is indicated in the below table 5.1 and figure 5.1

Table 5.1 : Simple payback period at different pricing levels and luminous efficacy levels

Price per klm (1000 LKR)	**Luminous efficacy (lm/W)**					
	80	**100**	**120**	**140**	**160**	**180**
6.0	40	11	7	6	5	5
5.5	36	10	6	5	5	4
5.0	31	8	6	5	4	4
4.5	27	7	5	4	3	3
4.0	22	6	4	3	3	3
3.5	18	5	3	3	2	2
3.0	13	3	2	2	2	2
2.5	9	2	2	1	1	1
2.0	4	1	1	1	1	0

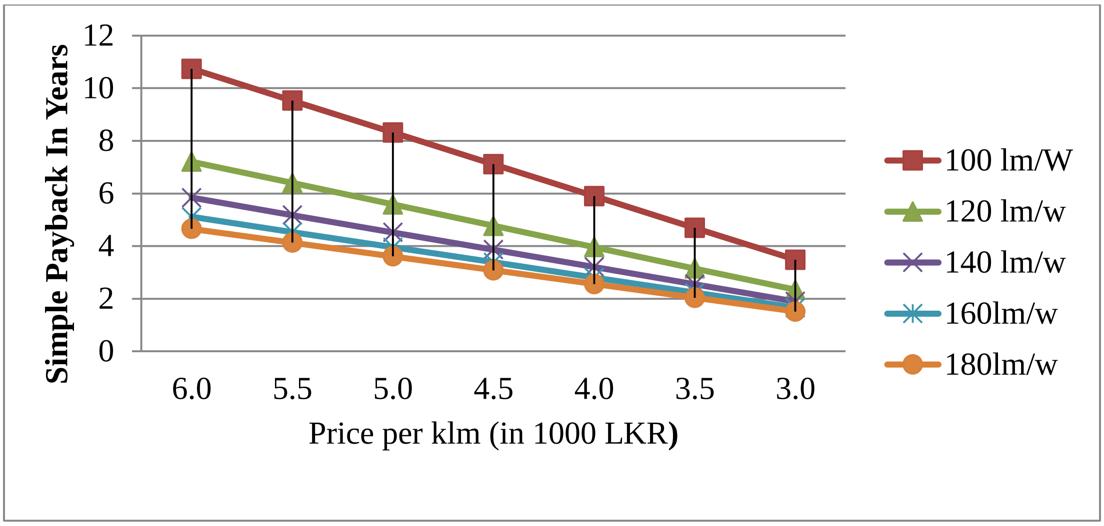

Figure 5.1 : Graph of price per klm Vs payback period at different luminous efficacies

5.3 Simple Payback Calculation Sensitivity Analysis Scenario 2

As explained earlier the simple payback was calculated with the variation of energy cost the lighting system. The results of the calculation is indicated in the below table 5.2 and figure 5.2

Table 5.2: Simple payback period at different energy cost levels and luminous efficacy levels

Energy Cost LKR/kWh	**Luminous efficacy (lm/W)**					
	80	**100**	**120**	**140**	**160**	**180**
15.0	61	17	12	10	8	8
20.0	48	13	9	7	6	6
25.0	40	11	7	6	5	5
30.0	34	9	6	5	4	4
35.0	30	8	5	4	4	3
40.0	27	7	5	4	3	3
45.0	24	6	4	3	3	3

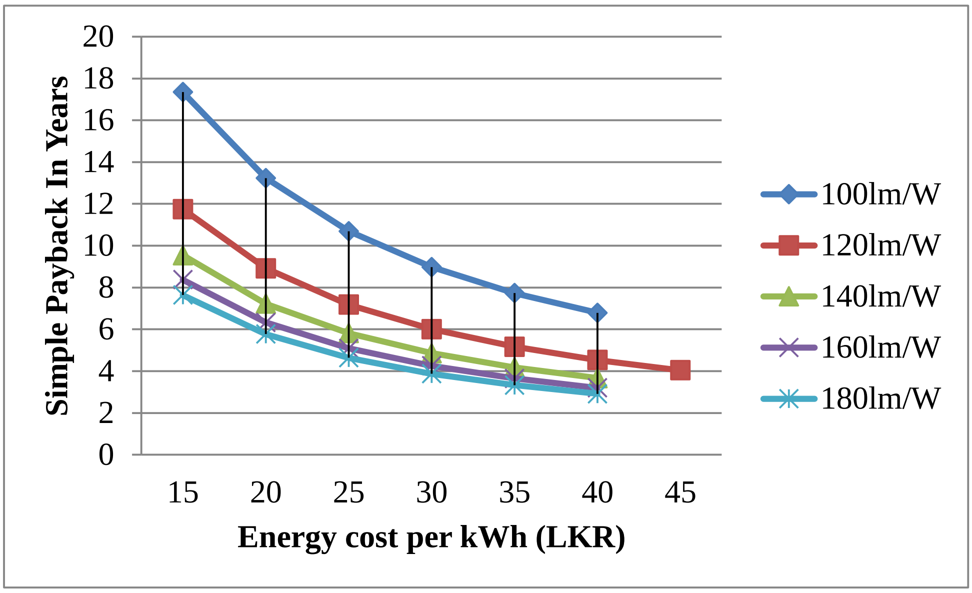

Figure 5.2: Graph of energy cost per kWh Vs payback period at different luminous efficacies

5.4 Simple Payback Calculation Sensitivity Analysis Scenario 3

As explained earlier the simple payback was calculated with the variation of annual operation hours of the lighting system. The results of the calculation is indicated in the below table 5.3 and figure 5.3

Table 5.3 : Simple payback period at different annual operating hours and luminous efficacy levels

Annual operating hours	**Luminous efficacy (lm/W)**					
	80	**100**	**120**	**140**	**160**	**180**
100	110	38	27	22	19	18
200	70	21	14	11	10	9
300	51	14	9	8	7	6
400	40	11	7	6	5	5
500	33	9	6	5	4	4
600	28	7	5	4	3	3
700	25	6	4	3	3	3

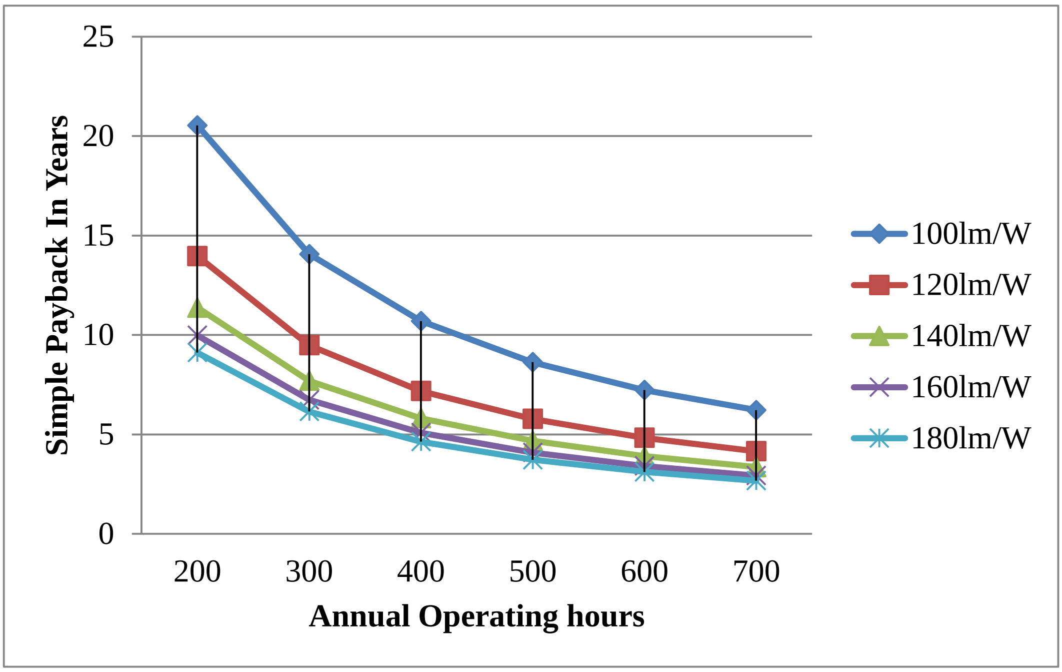

Figure 5.3 : Graph of operating hours Vs payback period at different luminous efficacies

5.5 IRR Calculation Sensitivity Analysis Scenario 1

As explained earlier the IRR was calculated with the variation of pricing of LED luminaires. The results of the calculation is indicated in the below table 5.4 and figure 5.4

Table 5.4: IRR at different pricing levels and luminous efficacy levels

Price per klm (1000 LKR)	**Luminous efficacy (lm/W)**					
	80	**100**	**120**	**140**	**160**	**180**
6.0	-6%	-5%	-4%	-2%	-1%	1%
5.5	6%	8%	9%	12%	15%	19%
5.0	11%	13%	15%	18%	22%	28%
4.5	15%	17%	19%	23%	27%	34%
4.0	17%	19%	22%	26%	31%	39%
3.5	19%	21%	24%	28%	34%	42%
3.0	-6%	-5%	-4%	-2%	-1%	1%
2.5	6%	8%	9%	12%	15%	19%
2.0	11%	13%	15%	18%	22%	28%

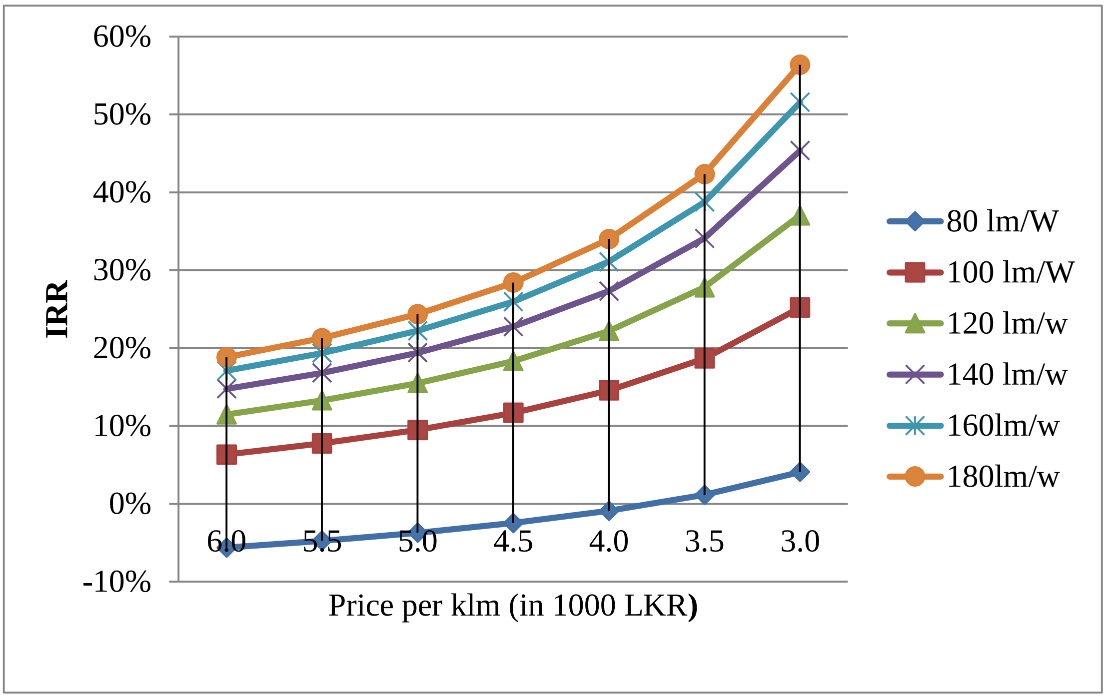

Figure 5.4: Graph of price per klm Vs IRR at different luminous efficacies

5.6 IRR Calculation Sensitivity Analysis Scenario 2

As explained earlier the IRR was calculated with the variation of energy cost the lighting system. The results of the calculation is indicated in the below table 5.5 and figure 5.5

Table 5.5: IRR at different energy cost levels and luminous efficacy levels

energy cost LKR/kWh	**Luminous efficacy (lm/W)**					
	80	**100**	**120**	**140**	**160**	**180**
15	-8%	2%	6%	9%	11%	12%
20	-6%	5%	10%	13%	15%	17%
25	-5%	8%	13%	17%	19%	21%
30	-4%	10%	16%	20%	23%	25%
35	-3%	12%	19%	23%	27%	29%
40	-2%	14%	21%	27%	30%	33%
45	-1%	16%	24%	30%	34%	37%

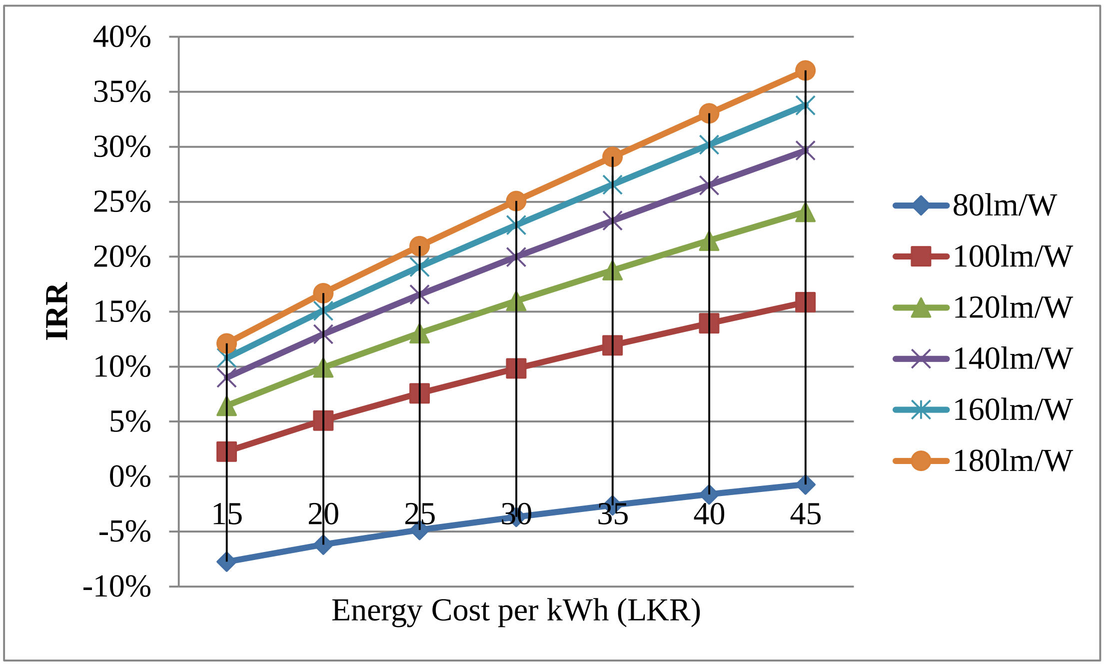

Figure 5.5 : Graph of energy cost per kWh Vs IRR at different luminous efficacies

5.7 IRR Calculation Sensitivity Analysis Scenario 3

As explained earlier the IRR was calculated with the variation of annual operation hours of the lighting system. The results of the calculation is indicated in the below table 5.6 and figure 5.6

Table 5.6: IRR at different annual operating hours and luminous efficacy levels

Annual operating hours	**Luminous efficacy (lm/W)**					
	80	**100**	**120**	**140**	**160**	**180**
100	-11%	-4%	-2%	0%	1%	2%
200	-9%	1%	5%	7%	8%	10%
300	-7%	4%	9%	12%	14%	16%
400	-5%	8%	13%	17%	19%	21%
500	-3%	10%	17%	21%	24%	26%
600	-2%	13%	20%	25%	28%	31%
700	-1%	15%	23%	29%	33%	36%

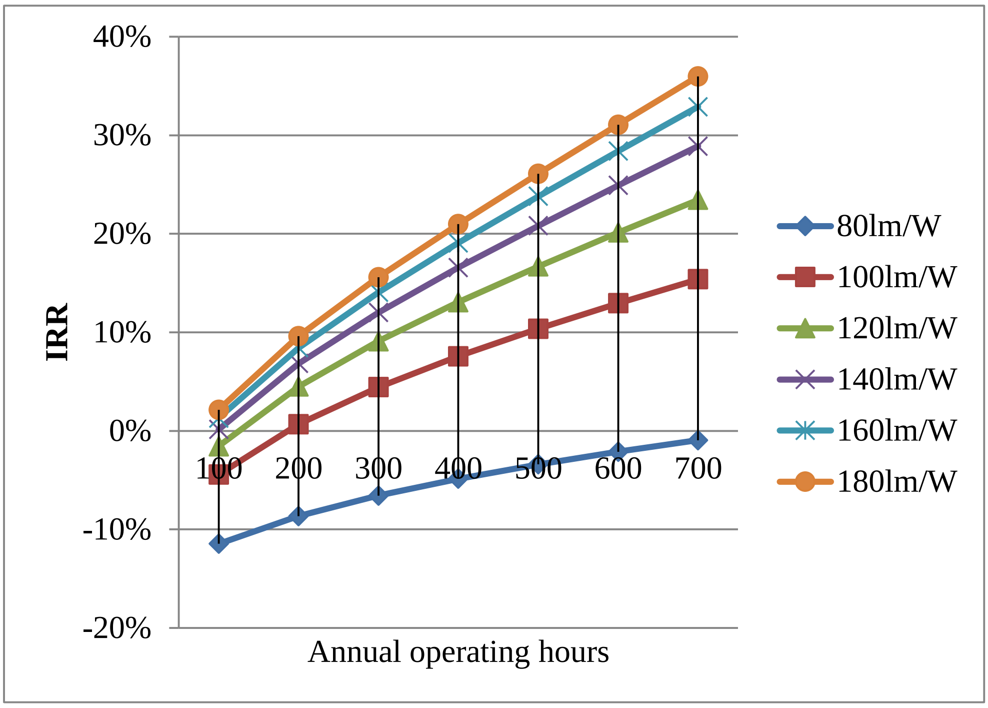

Figure 5.6 : Graph of operation hours Vs IRR at different luminous efficacies

5.8 Important Observations of Sensitivity analysis

From the above tabulated results of the sensitive analysis we can observe some important points.

If the 120lm/W efficacy of LED luminaire (which is 20% increase of current efficacy level which is 100lm/W) and price per klm drops to 5000 (reduction of 9% from current pricing level) payback will be 6 years and IRR is 15%. Further at the same efficacy level, if the price levels drop to 4500 per klm (reduction of 20% from current level) will be around 5 years & IRR is 19%. Hence we can conclude that LED solution will be feasible at efficacy level of 120lm/W and pricing lower than 5000 LKR per klm.

Considering the operation hours of the lighting system at annual operation hours of 400 at 120lm/W luminous efficacy level payback will be around 7 years & IRR is 13%. Considering the 500 annual operation hours at 120lm/W efficacy level payback will be around 6 years & IRR is 17%. This is with regards to current pricing level and these values will improve with future price reductions. Hence we can conclude that LED solution will be more suitable for stadium that operate their flood lighting system for at least 400 hours per year.

Chapter 6

QUALITATIVE ANALYSIS

In the earlier chapter a quantitative analysis was done for conventional and LED lighting systems for a sports application. However apart from energy savings and reduction of maintenance expenses (due to longer life time) LEDs have some other advantages which cannot be included in a quantitative analysis. Therefore in this chapter those advantages will be discussed qualitatively.

6.1 Ability to Start Instantly

Since LED is a solid state technology it will deliver its full lighting output from the moment it was switched on. In contrast the conventional metal halide lampas used for sports applications generally take 5-10 minutes to reach to its full light output. Since the metal halide lamps are discharge lamps, until its inner arc tube reaches the required temperature and gas pressure builds up, the lamp will not deliver the full light output. Therefore metal halide lamps need to be switched on prior to the event so that they will be delivering the full light when the sports event start, however LEDs do not need such warming up times so that they can be switched on as and when the lights are needed.

There is another problem with metal halide lamps in case of a sudden power failure. Even after a very brief power failure the lamp needs to be cooled down completely before it can be switched on again. The reason for this is the high pressure inside the tube prevent the igniter restriking the arc. However some of the metal halide lamps used in sports lighting applications have the hot restrike feature where they use special igniters to restrike the arc while the tube is hot. In the cases where this feature is not in the bulb a sudden power failure means that the stadium will have no light for about five minutes even though the power is restored. LED luminaires however can be switched on immediately after the power is restored.

6.2 Reduction of Starting Current

Generally the ballasts with discharge lamps have a higher inrush current (the current which is drawn at the time of starting of the lamp) which is at least 4-5 higher than the rated current. This extremely high current will flow for a very short period of time, however this factor has to be taken into consideration when selecting cables

and breakers for the power distribution system since these components need to withstand the high current. Since most of the stadium lighting systems are powered by diesel generators this factor has to be considered when selecting a generator as well. In general practice to reduce the effect of the inrush currents luminaires, all the luminaires are not switched on at once. They are switched on in small groups with a delay. This is either done manually or with the use of an automated system.
However in good quality LED luminaires there is no significant variation in the inrush current from the rated current, therefore all the above described additional considerations and precautionary practices will not be required.

6.3 Reduction of Flicker

Since most of the conventional metal halide luminaires operate with electromagnetic ballasts these lamps have a variation of light output with the frequency of 100 Hz (at 50Hz supply frequency) which is not visible to naked human eyes. But this flicker is identifiable in television broadcasting in slow motion shots. The solution to this flickering is either using electronic ballasts which have higher operating frequencies so that flickering rate is higher. However electronic ballast for 1000W and 200W lamps are very expensive. There is another solution to this which is balancing the luminaires in the three phases so that at any given moment there will be sufficient amount of luminaires switched on to give the required lighting output to the cameras.
The flicker on the sports field is measured by Flicker factor. Flicker factor is defined as

$$FF = \left(\frac{E_{H\,max} - E_{Hmin}}{E_{Hmax} + E_{Hmin}}\right) \times 100\%$$

where
FF is the flicker factor (%),
$E_{H\,min}$ is the minimum horizontal illuminance in time at point on the calculation grid (lux)
$E_{H\,max}$ is the maximum horizontal illuminance in time at the corresponding point on the calculation grid (lux).
The phase balancing method explained earlier will only solve the flickering problem for television broadcasts done with super slow motion (SSM) cameras with speeds of 150-600 fps (frames per second). However today HDTV broadcasts use ultra slow

motion (USM) cameras which have frame speeds upto 1000fps. For these slow motion shots flicker factor should be at least less than 6%. In such cases metal halide luminaires need to use very special electronic ballasts and igniter systems to achieve the flicker rate requirements.

However in LED luminaires controlling the flicker is quite easier compared to discharge lamps. Since LED luminaires are running on direct current (DC) the LED luminaires will not be switched on and off. However since the supply DC voltage/current is converted from alternate current (AC) there will be a ripple in the DC current/voltage. If necessary smoothing mechanisms are used in the LED driver the flicker can be controlled easily. Therefore LED luminaire will have less amount of flicker when compared with conventional metal halide lighting.

6.4 Uniformity and Glare Control

Since the LEDs are point sources and LED luminaire consists of many small LEDs it is easier to control the light beam when it is compared with the metal halide lamps which is an Omni-directional large lamp source. Usually in metal halide luminaires used for sports light applications have very special features to control the glare and to achieve the required beam angles. However in LED luminaires glare control and required beam angles can be achieved easily due the directionality and compact size of the LED source.

In the literature review in Chapter 1 it was observed that in the research conducted by Boxler [1], he has observed that LED lighting had better uniformity and less glare control when compared with metal halide.

Also due to the controllability of the LED light beam, the light can be directed exactly to the pitch of the stadium and the amount of light traveling to other directions is very less. Hence the lighting pollution caused by light travelling to unintended areas in the environment is also relatively low when compared to metal halide lighting.

Chapter 7

CONCLUSION

Analyzing the results we obtained at the economic analysis and the sensitivity analysis we can come to following conclusions.

In current context under prevailing price levels and performance of LED fixture (100lm/W) does not justify its expensive pricing (5500 LKR per klm) when compared with its closest competitor, metal halide (78lm/W, 1500 LKR per klm). Therefore LED solution is not feasible at the current situation.

However with decrement of pricing of LED at around 5000-4500 LKR per klm (10%-20% reduction of current value), if the efficacy of the product also increase to 120lm/W LED solutions will be feasible. It is important to note that already there are many LED products which have luminaire luminous efficacy of 120lm/W. Therefore specialized sports luminaires will also achieve these efficacy levels in the near future.

With the decrement of pricing and increment of efficacy levels, LED solutions will be feasible in future to stadiums that has an energy cost is more than 25 LKR per kWh.

With the decrement of pricing and increment of efficacy levels, LED solutions will be feasible in future to stadiums that use flood lighting at least for more than 400 hours per year

In addition to that as we have discussed in the qualitative analysis there will be some additional advantages of LED lighting system in sports lighting application such as ability to start instantly, reduction of starting current, better uniformity, less glare and lesser flicker. It is important to note that these factors have not been considered in the main analysis we have done since they cannot be quantified

As the final conclusion we can conclude that although LED lighting is not quite feasible in sports lighting application under current scenario, with the performance improvement of the LED technology and price reduction of the LED luminaires (as mentioned above) it will be feasible in the near future specially for the stadiums that operate under lights for more than 400 hours annually.

Reference List

[1] L. Boxler, "Optical Design and Lighting Application of an LED-Based Sports," *Proc. SPIE 8123, Eleventh International Conference on Solid State Lighting,,* vol. 9578, 2011.

2[2] Fédération Internationale de Football Association (FIFA), Football Stadiums Technical Recommendation and Requirements, Fédération Internationale de Football Association (FIFA).

[3] L. Tähkämö, R.-S. Räsänen and L. Halonen, "Life cycle cost comparison of high-pressure sodium and light-emitting diode luminaires in street lighting," *The International Journal of Life Cycle Assessment,* vol. 21, no. 2, p. 137–145, 2016.

[4] X.-H. Lee, J.-T. Yang, W.-T. Chien, . J.-H. Chang, Y.-C. Lo, C.-C. Lin and C.-C. Sun, "High-performance LED luminaire for sports hall," *Current Developments in Lens Design and Optical Engineering XVI,* vol. 9578, 2015.

[5] Philips Lighting, *Lighting Specification Cricket International Level,* Miribel, 2006.

Appendix A

Methodology Followed in Sports Lighting Design using Calculux Area Software

Step 1:

The drawing of the sports stadium is imported to the software and the any obstacles that will be relevant to the lighting calculation are defined as indicated in figure A.1 and A.2

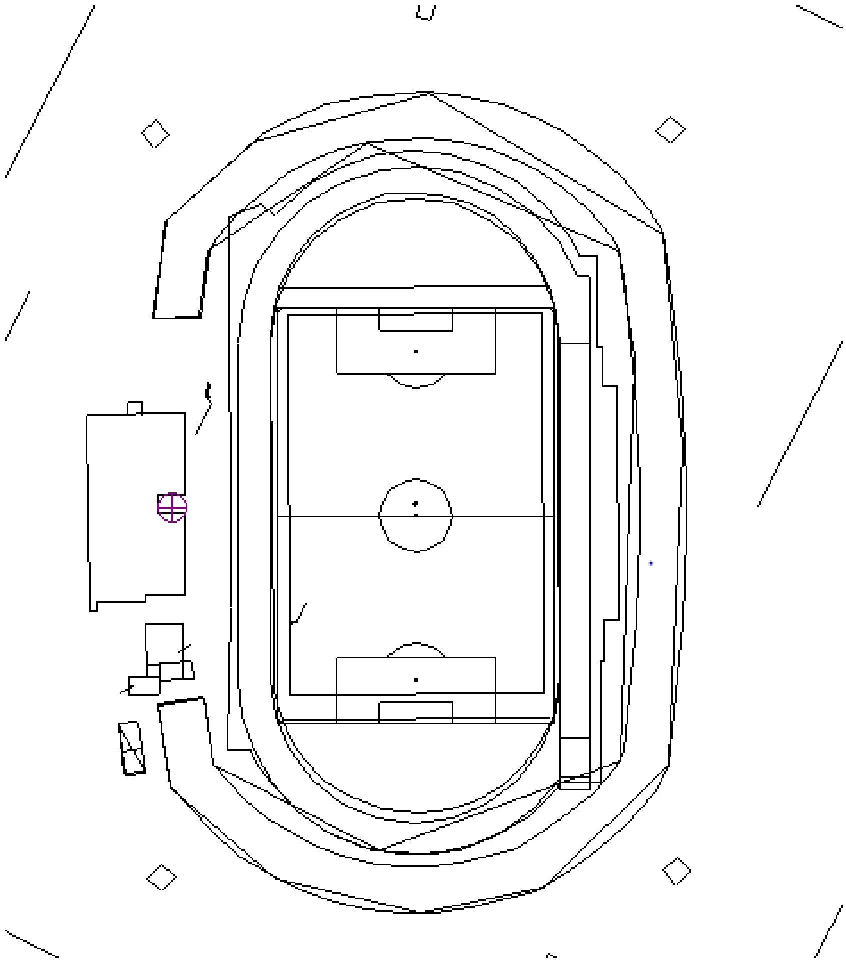

Figure A.1: Importing site plan to software

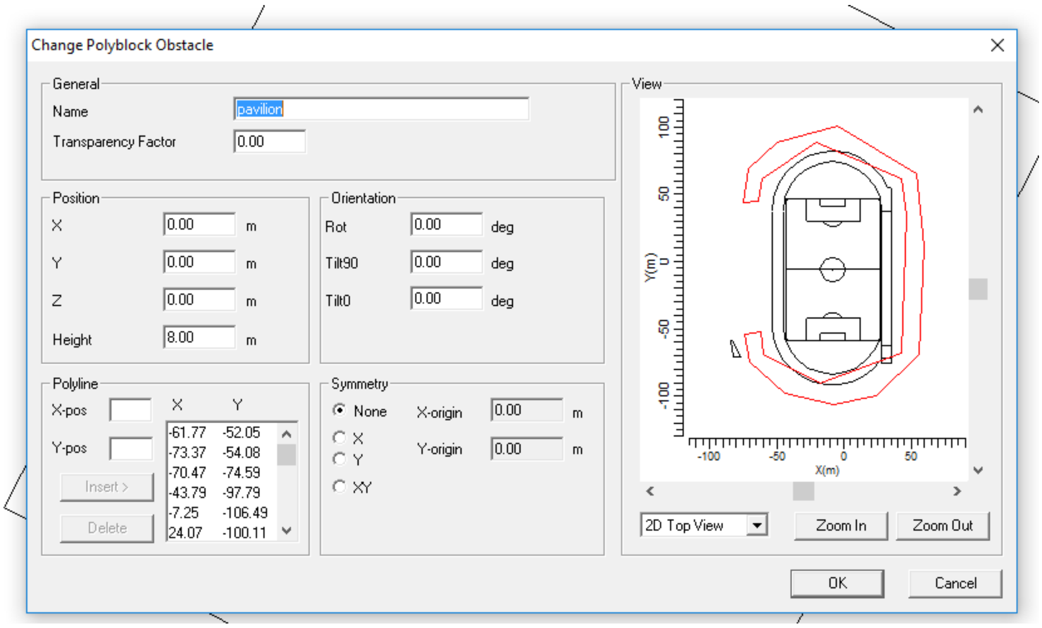

Figure A.2 Creating obstacles

Step 2:

The application fields (sports fields) where the calculation will be done and calculation grids to be considered are defined as indicated in figure A.3 and A.4.

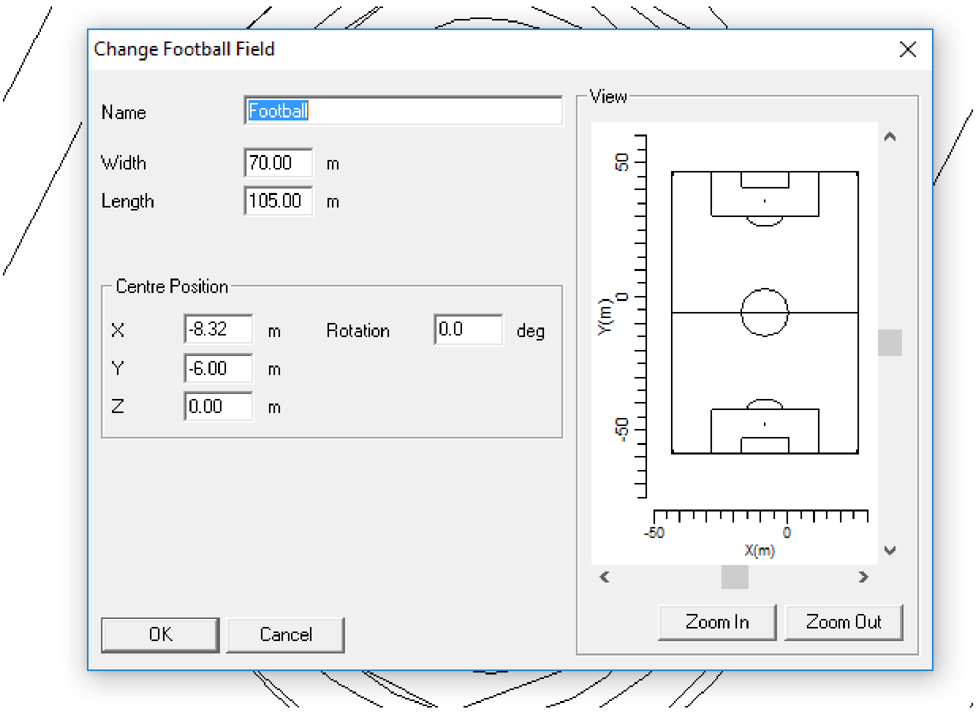

Figure A.3: Defining application fields

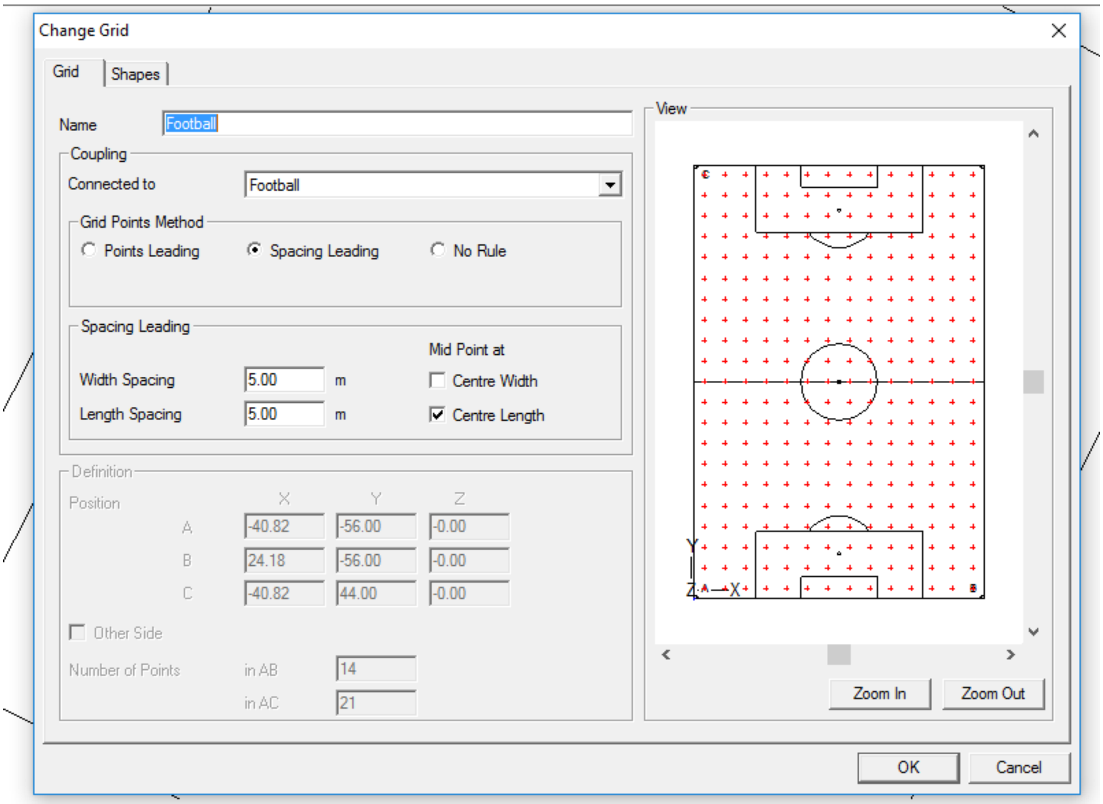

Figure A.4: Defining calculation grids

Step 3:

If vertical lux level calculations are done relevant observers are defined as indicated in figure A.5.

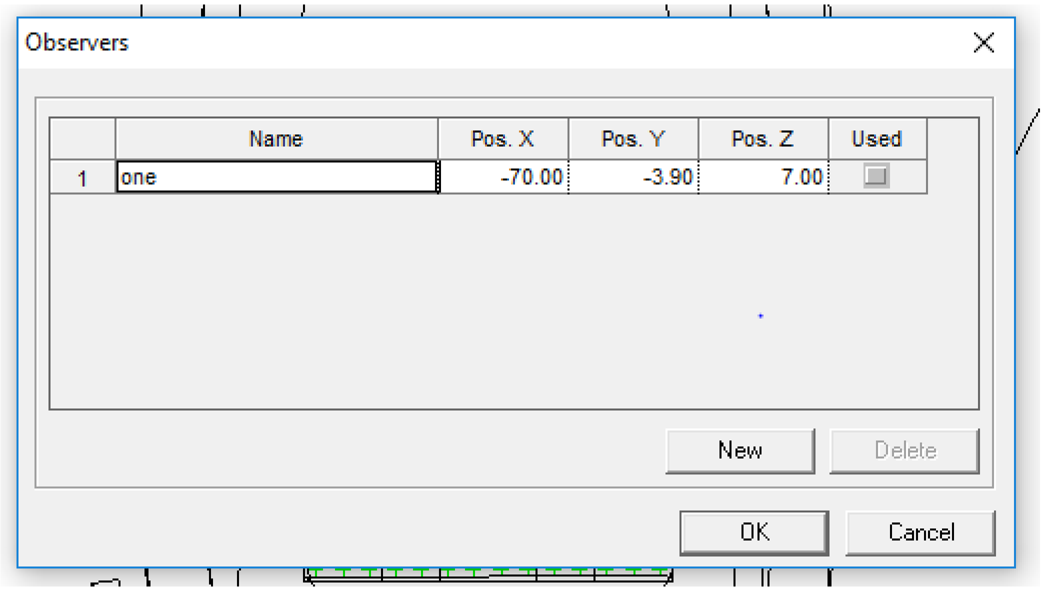

Figure A.5: Defining observers

Step 4

The calculation (horizontal, vertical) that should be performed are defined as indicated in Figure A.6

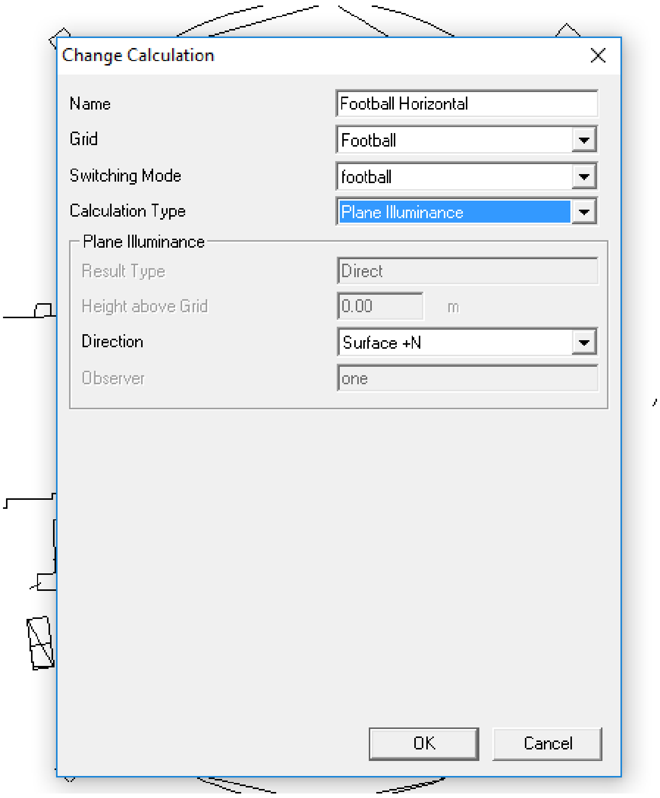

Figure A.6 Defining calculation grids

Step 5

The photometry files of luminaires used for the design are imported to the software as indicated in Figure A.7.

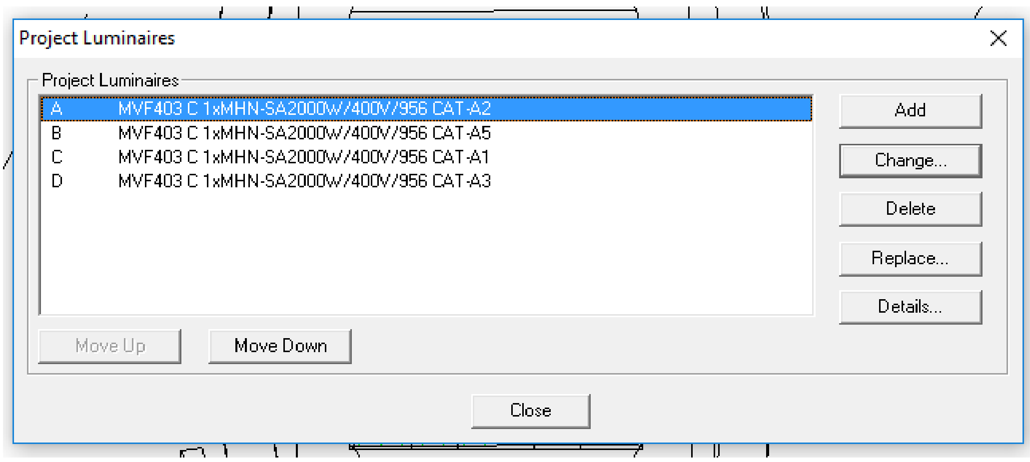

Figure A.7: Importing photometry files of the luminaires

Step 6

Mast positions of the stadium are defined. Usually if the masts are symmetrical one mast is defined with a centre point as indicated in Figure A.8. Then other masts are automatically created.

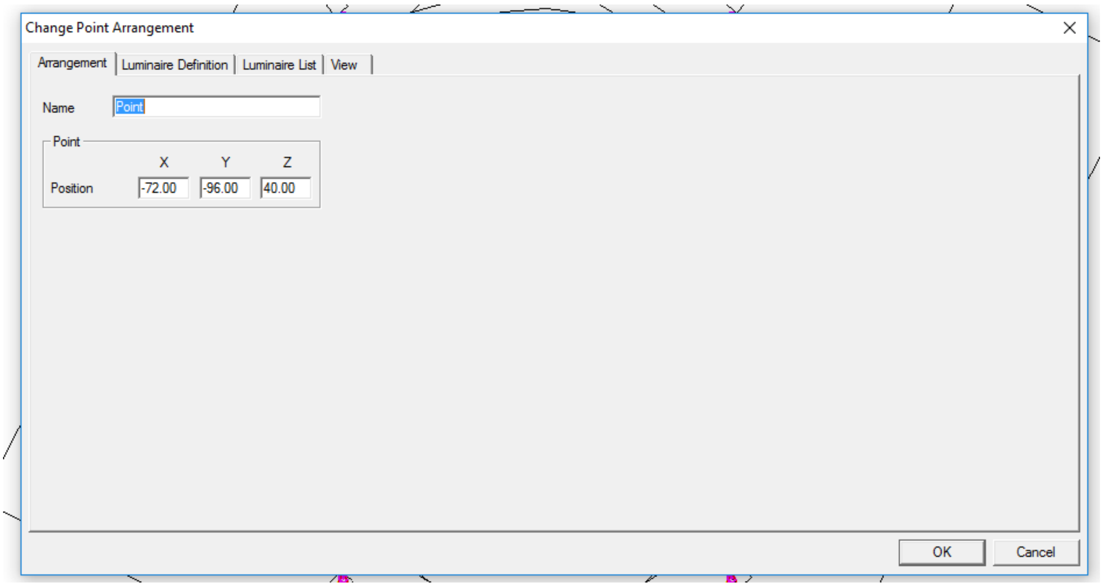

Figure A.8: Defining mast position

Step 7

Then luminaires are added to the mast one by one with the relevant details. Aiming of the luminaires can be done by defining the coordinates of the aiming point or manually as indicated in Figure A.9 and A.10,

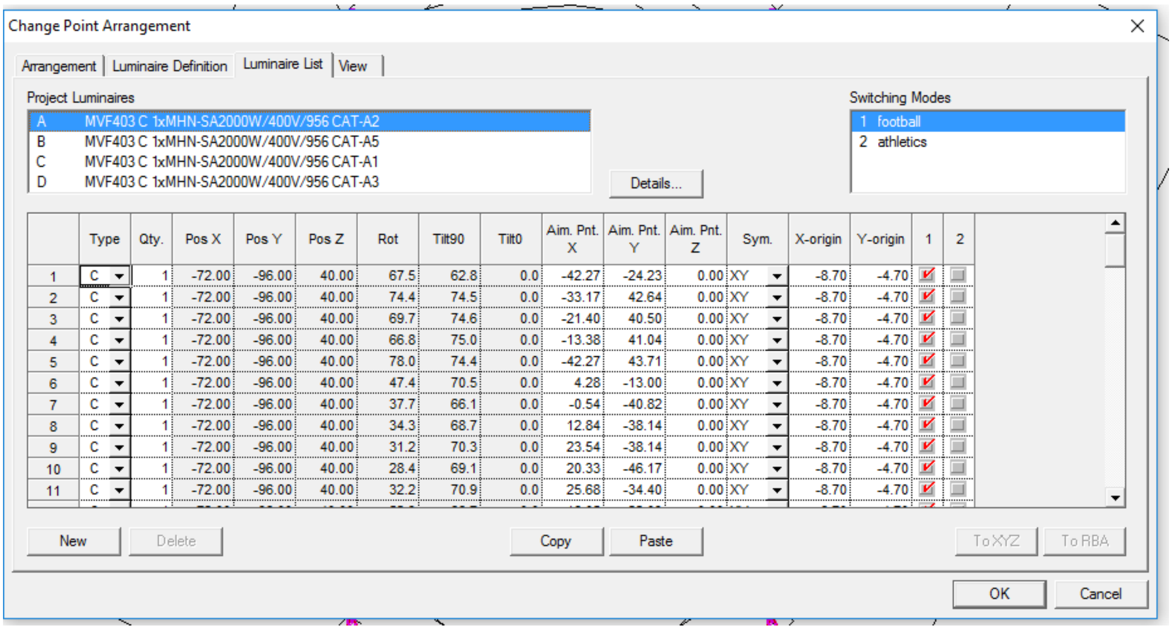

Figure A.9: Adding luminaires to the mast

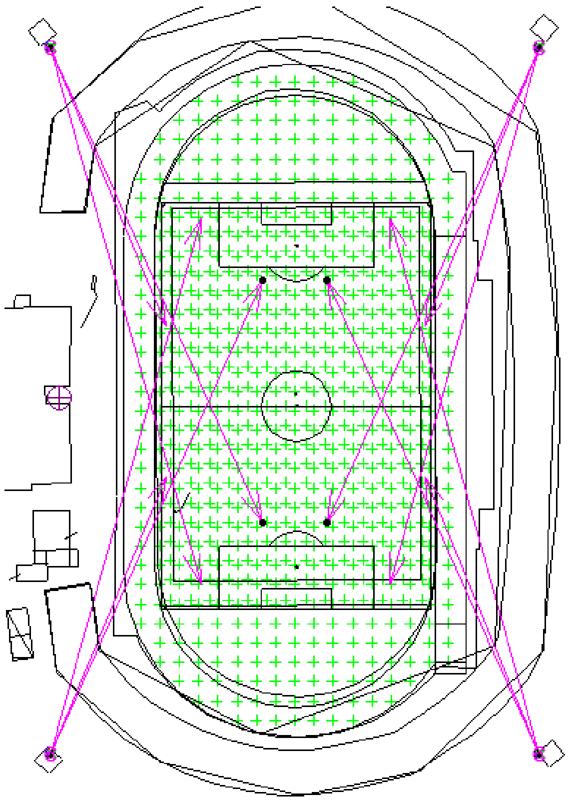

Figure A.10: Aiming luminaires manually

Step 8

After all the required luminaires are added calculation is performed. The calculation results can be viewed as a summary or in various graphical illustrations such as iso-contour maps, graphical table etc as indicated in Figure A.11

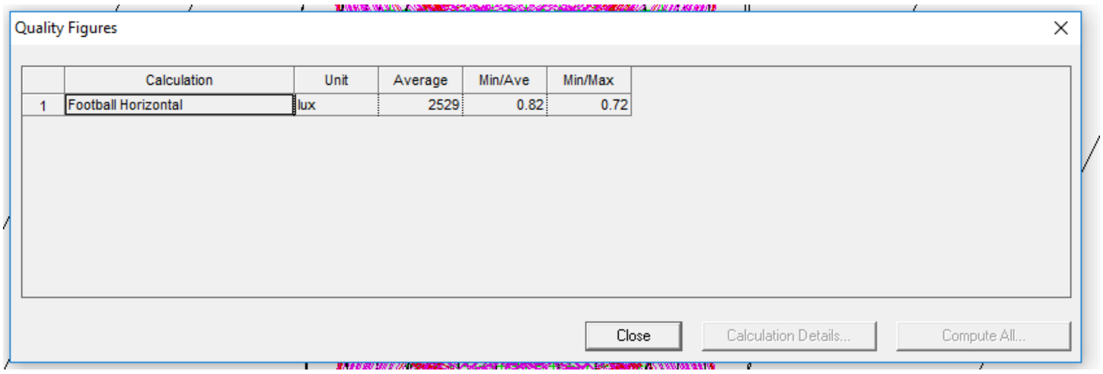

Figure A.11: Summary of results