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Multiple optical parameters improvisation for outdoor sport lighting by t-test method

***Abstract**. The standard lighting design softwares are essentially calculating tools without any optimizing features. Use of these softwares lead to trial & error based iterative design approach. This however produces a set of interim design solutions consisting of appropriate or inappropriate design cases. In this paper, a statistical method, t-test, is successfully applied on these interim design solutions. Hence the list of Determinant Luminaires (DLs) and corresponding Optimized Aiming Angles (OAAs) are identified to enhance multiple optical parameters for the inappropriate design cases.*

***Keywords:** Determinant Luminaires (DLs), Optimized Aiming Angles (OAAs), Sports Lighting, t-test.*

Introduction

In outdoor sports lighting designing, the luminaires are mounted around the sports arena to provide an appropriate luminous environment by controlling the brightness of an object and its background, so the object appears clear and sharp to the players, stadium viewers and television viewers. There are standard *lighting designing softwares* available, like – Calculux, Dialux, Europic, AGI32 etc. for initial simulation of lighting design for any indoor and outdoor application [1, 2] area. However the lighting designing softwares are basically calculating tools only without any optimizing features. It often becomes very difficult to determine the suitable aiming angles [3] for the luminaires to achieve the preferred optical parameters [1, 4] in single attempt. Thus it leads to a *'trial and error'* based iterative designing process which primarily depends on the skills of the lighting professional or designer and a pool of interim design solutions get evolved. In this context, t-test [5, 6] based approach has been taken to select the *Determinant Luminaires (DLs)* and corresponding *Optimized Aiming Angles* (OAAs) from the pool of interim design solutions. The multiple-optical parameters [7-11] e.g., Average Horizontal Illumination (E_H), Average Vertical Illumination (E_V), Horizontal Overall Uniformity ($U_{0H} = E_{H\text{-}min}/E_H$), Horizontal Transverse Uniformity ($U_{1H} = E_{H\text{-}min}/E_{H\text{-}max}$), Vertical Overall Uniformity ($U_{0V} = E_{V\text{-}min}/E_V$), Vertical Transverse Uniformity ($U_{1V} = E_{V\text{-}min}/E_{V\text{-}max}$) are improvised by readjusting DLs with corresponding OAAs both in *horizontal & vertical* plane. The improvement of lighting design quality is also evaluated by the measure of Coefficient of Variation ($CV = \sigma/\bar{x}$) [11]. However, CV depends on the values of illuminance throughout the field, meaning CV is regarded as a good indicator of the overall uniformity. A case study was conducted on Yuvabharati Football Stadium, Kolkata, India to explain and evaluate performance of the t-test based outdoor sports lighting desining application.

Steps for Outdoor Sports Lighting & Data preparation

The iterative designing process for any outdoor sports lighting facility can be divided into five basic steps

Step I: Select lighting standards or recommendations in terms of multiple-optical parameters as per *Class & Group of play* [2].

Step II: Depending on the recommended values of optical parameters, calculate the approximate quantity of luminaires using Lumen Method [3, 12] for a given sports arena.

Step III: Define luminaire mounting arrangements based on provided data or considering all relevant constrains.

Step IV: Aim the luminaires of (+X,+Y) quadrant [12], towards the field. The luminaires in other quadrans are put into double axis symmetry. Simulation is done for the sports lighting design using any lighting design software.

Step V: Check whether the multiple-optical parameters are matching with the standards recommended values or not.
If it matches, the design is *'appropriate'*;
Otherwise, the design is '*inappropriate'* and the designing procedure starts again from Step IV by reaiming individual luminaires.

However it is difficult to say in how many attempts an appropriate design can be prepared. Thus a pool of interium design solutions gets evolved due to itterative design process. The Yuvabharati Football stadium lighting design is done for thirty times in Calculux [13] by following the above steps. Thus a pool of thrity interim design solutions are prepared, consisting both approproite and inappropriate design cases. There are total 448 numbers of luminaires being used in the designs and each quadrant of the field comprises of 112 luminaires. The (+X,+Y) quadrant luminaires are again sub-divided into 16 different sub-sets. However The luminaires in (+X,+Y) quadrant are symbolized by L1, L2,..., L112 and Table 1 indicates the categorization of luminaires according to 16 subsets [6]. The rows of Table 1 indicates each luminaire set and corresponding luminaires included in that particular set.

Table 1. Sixteen different luminaire sets of Yuvabharati Football Stadium in (+X,+Y) quadrant

Set	**Lumianires in (+X,+Y) quadrant**							
1	L1	L2	L3	L4	L5	L6	L7	L8
2	L9	L10	L11	L12	L13	L14	L15	L16
3	L17	L18	L19	L20	L21	L22		
4	L23	L24	L25	L26	L27	L28		
5	L29	L30	L31	L32	L33	L34		
6	L35	L36	L37	L38	L39	L40		
7	L41	L42	L43	L44	L45	L46		
8	L47	L48	L49	L50	L51	L52		
9	L53	L54	L55	L56	L57	L58	L59	L60
10	L61	L62	L63	L64	L65	L66	L67	L68
11	L69	L70	L71	L72	L73	L74	L75	L76
12	L77	L78	L79	L80	L81	L82	L83	L84
13	L85	L86	L87	L88	L89	L90	L91	L92
14	L93	L94	L95	L96	L97	L98	L99	L100
15	L101	L102	L103	L104	L105	L106		
16	L107	L108	L109	L110	L111	L112		

The aiming of the luminaires in (+X,+Y) quadrans of the field are done depending on their beam angle and skills of the designer. However the vertical aiming angles of the luminaires are kept within certain values to avoid light pollution [3, 11]. The horizontal aiming angles of the luminaires are symbolized as L1_X, L2_X, ..., L112_X and the vertical aiming angles are symbolized as L1_Y, L2_Y,

…., L112_Y. In Table 3, sample horizontal & vertical aiming angles corresponding to two luminaires in (+X,+Y) quadrant for thirteen design cases out of thirty different design cases are shown for Yuvabharati Football Stadium. The quality of the designs are also measured in terms of CV. The sample values of optical parameters, alongwith CV, for 30 interim design cases are presented in Table 3.

Table 2. Luminaires aiming angles in horizontal & vertical plane for Yuvabharati Football Stadium in (+X,+Y) quadrant for interim designs

Design Case	L1_X (^{0})	L1_Y(^{0})	-	L112_X (^{0})	L112_Y (^{0})
1	49.4	68.7	-	93.9	59.7
2	51.8	71	-	93.9	59.7
3	49.4	68.7	-	84.9	59.7
4	49.4	68.7	-	93.9	59.7
5	49.4	68.7	-	93.9	59.7
-	**-**	**-**	-	**-**	**-**
10	51.1	69.1	-	93.9	59.7
11	61.6	70.4	-	82.5	53.4
12	41.5	45	-	97.7	49.1
13	49.4	78.2	-	93.9	59.7
-	-	-	-	-	-
27	27.2	61.9	-	93.9	59.7
28	45	61.2	-	93	59
29	49	68.7	-	84.2	59.7
30	50.3	68.2	-	90.5	58.3

Table 3. Simulated results of Optical Parameters for Yuvabharati Football Stadium

Design Case	E_H (lux)	U_{0H}	U_{1H}	E_V (lux)	U_{0V}	U_{1V}	CV
1	3503	0.9	0.8	2803	0.8	0.7	0.01
2	3643	0.7	0.6	3016	0.7	0.5	0.03
3	3558	0.8	0.8	2915	0.8	0.6	0.02
4	3672	0.7	0.6	3029	0.7	0.6	0.02
5	3526	0.8	0.8	2842	0.8	0.6	0.01
-	-	-	-	-	-	-	**-**
10	3642	0.7	0.6	3017	0.7	0.6	0.03
11	2686	0.6	0.3	1998	0.6	0.4	0.15
12	2623	0.4	0.3	1695	0.3	0.2	0.08
13	2691	0.6	0.5	2134	0.5	0.3	0.02
-	-	-	-	-	-	-	-
27	2660	0.4	0.3	2094	0.5	0.2	0.11
28	3579	0.7	0.6	2718	0.7	0.5	0.03
29	3606	0.8	0.8	2919	0.8	0.6	0.02
30	3630	0.8	0.7	2762	0.7	0.5	0.02

Problem Statement

There are 30 interim design solutions for Yuvabharati Football Stadium. However among these design cases all the designs are not of same quality. Hence according to the preferred reference values of the optical parameters, the interim design cases can be categorised as shown in equation (1).

$$DesignCase(n) = \left\{ \begin{array}{l} \text{Appropriate} \\ \quad E_H \geq 3400\,\text{lux}; U_{0H} \geq 0.7; U_{1H} \geq 0.5; \\ \quad E_V \geq 2700\,\text{lux}; U_{0V} \geq 0.7; U_{1V} \geq 0.5 \\ \text{Inappropriate} \\ \quad E_H \langle\, 3400\,\text{lux}; U_{0H} \langle\, 0.7; U_{1H} \langle\, 0.5; \\ \quad E_V \langle\, 2700\,\text{lux}; U_{0V} \langle\, 0.7; U_{1V} \langle\, 0.5 \end{array} \right\} \quad (1)$$

where 'n' indicates interim design solution number.

Thus from Table 3 it can be obtained that the interim design case no.11 to no.27 are inappropriate designs and rest of the designs are appropriate ones. Again the CV for few inappropriate designs exhibits alarming values (CV>0.13). It is significant to mention here that although same set of luminaires are used for all the interim design solutions but due to improper aiming of few pertinenet luminaires, there is wastage of artificial light and degradation in multiple optical parameters. In this context t-test is applied on these 30 interim design solutions to identify those pertinent luminaires or DLs. Also the OAAs are calculated to improvise the multiple optical parameters and CV. This may lead to convertion of few inappropriate design cases to appropriate ones.

t-test

The t-test [14-17] is known as *Null hypothesis testing* [6, 14] which utilizes the concept of *probability* [6, 14]. The raw data is analyzed to decide whether to '*reject*' or '*not to reject*' null hypothesis H_0 and for this purpose, 't-test' is used to find the sampling distribution, assuming H_0 is really true. This decision about rejection or acceptance of H_0 is based on probability considerations. The observed t value in the sample is generally different from the expected value because of sampling fluctuations. If the difference between them is large, H_0 is rejected & if the difference is not large, H_0 is not rejected and the difference may be considered.

The interim design solutions are the Population and the aiming angles (both horizontal & vertical) associated with luminaires are the *Samples* for which the 't' values are calculated. It is assumed that a normal distribution exists and the probability of a particular outcome can be identified. If the 't' value for a luminaire is measued beyond critical value range, the luminaire is identified as DL. The OAAs are also calculated during the 't'value calculations process for the interim design solutions.

Application of t-test

There are 112 numbers of luminaires in (+X,+Y) quadrant of the field which are sub divided into 16 sets. Thus t-test is applied on these 16 sets individually. The algorithm of t-test is hence described to identify the DLs and corresponding OAAs.

Input: Matrix representing horizontal & vertical aiming angles of the luminaires where each row represents a interim design case no. & each column represents a luminaire's aiming angles.

Output: List of DLs & OAAs.

Step 1: State the level of significance of the test & the corresponding reference t-value.

Step 2: Calculate *degree of freedom* (d.f.) [6] & *Population mean* μ [6] (Average of the total set of luminaire aiming angle in the matrix).

Step 3: Calculate mean $\bar{x}$, *standard deviation* s [6] & *standard error* [6] for aiming angles of each luminaire.

Step 4: Calculate 't' distribution for aiming angles of each luminaire as $t = \dfrac{\bar{x} - \mu}{s / \sqrt{n-1}}$

Step 5: Determine the boundary conditions using the d.f. & the level of significance.

Step 6: **If**

$t \leq$ Boundary values

Null Hypothesis is *true*. Hence *reject* the corresponding luminaire.

Else

Null hypothesis is *false*. Hence reject the population mean μ and *select* the corresponding luminaire as DL.

End.

Among 16 luminaire sets, the horizontal aiming angles of Luminaire Set 1 (consisting eight luminaires L1 to L8) is used to describe sample t-test calculation for selecting the DLs. Thus Table 4 is divided into two parts. The first part describes the horizontal aiming angles of luminaires L1_X to L8_X in (+X,+Y) quadrant of the stadium for all interim design solutions. In the next half of Table 4, the t-test calculation is explained for the luminaires and hence DL selection process. According to the algoritm the 't' values individual for luminaires are calculated. The *critical value* [6] for acceptance or rejection is 1.7, according to the probability of 5%. Thus depending on the individual 't' values of each luminaires, either the luminaire gets accepted or rejected with respect to range of critical value. Subsequently the last row indicates the total seven accepted luminaires or DLs (L1_X to L3_X & L5_X to L8_X). As an example, it can be explained from Table 4 that the 't' value (1.53) of luminaire 'L4_X' is within the range of *critical value* (± 1.7). Thus the horizontal aiming variation of this particular luminaire (L4) does not affect the design optical parameters significantly. Hence this method is used to identify the *DLs* from the Luminaire Set 1. Similarly all the DLs for all the sixteen sets of luminaires are identified based on horizontal and vertical aiming angles.

Table 4. Simulated results of Optical Parameters for Yuvabharati Football Stadium

Design Case	L1_X (^{0})	L2_X (^{0})	L3_X (^{0})	L4_X (^{0})	-	L7_X (^{0})	L8_X (^{0})
1	49.4	12.2	30.7	42.3	-	12.6	68.1
2	51.8	14.5	30.7	41.7	-	14.2	65
3	49.4	12.2	30.7	42.3	-	14.2	68.1
4	49.4	14.9	35.8	44.2	-	15.4	68.1
-	-	-	-	-	-	-	-
27	27.2	9.5	23.6	54	-	12.7	69.3
28	45	20	28	34	-	14.6	70.1
29	49	12.4	30	42	-	14	68.4
30	50.3	13.9	26.2	42.3	-	11	67.5
t-test Calculation							
Mean (^{0})	**49.5**	**13.80**	**29.89**	**41.9**	-	**16.03**	**69.6**
STDEV (S)	**9.516**	**7.79**	**9.53**	**12.3**	-	**14.3**	**4.37**
Standard Error	**1.767**	**1.45**	**1.77**	**2.25**	-	**2.66**	**0.81**
Population Mean	**38.54**						
't' value	**6.20**	**-17.1**	**- 4.9**	**1.53**	**-**	**- 8.5**	**38.3**
significance point of 't' at p= 0.05	**1.7**						
results for p=0.05	**DL**	**DL**	**DL**	**X**	**-**	**DL**	**DL**

The DLs are identified from the aspect of their *mean aiming angle values* as have been calculated for all 30 interim design cases. Thus the DLs are assigned with their *mean aiming angles* values. These *mean aiming angle values* are the OAAs. Table 5 & Table 6 represents chosen DLs and corresponding OAAs for horizontal & vertical aiming angles respectively.

Table 5. Identified DLs corresponding to horizontal aiming angles and alongwith OAAs for Yuvabharati Football Stadium

Set	Luminaires	Angle (^{0})	Set	Luminaires	Angle (^{0})
1	LI_X	49.5	10	L61_X	46.9
	L2_X	13.8		L62_X	52.9
	L3_X	29.9		L64_X	36.4
	L5_X	32.1		L65_X	32.9
	L6_X	55.4		L66_X	13.2
	L7_X	16		L67_X	58.1
	L8_X	69.6		L68_X	63.3
2	L9_X	37	11	L69_X	30.2
	L10_X	44		L70_X	24.7
	L11_X	48.3		L71_X	14.2
	L12_X	53.7		L73_X	41.8
	L13_X	29		L74_X	70.1
	L14_X	10.8		L75_X	69.6
	L15_X	54.9		L76_X	17.1
	L16_X	49.4	12	L77_X	58
3	L17_X	106.3		L78_X	21.8
	L18_X	123.7		L79_X	66.2
	L19_X	113.6		L80_X	43.9
	L20_X	105.7		L81_X	53
	L21_X	129.1		L82_X	37.4
	L22_X	129.9		L83_X	57.4
4	L24_X	46.7		L84_X	55.1
	L25_X	107.6	13	L85_X	37
	L26_X	104.3		L86_X	27.9
	L27_X	112.2		L87_X	40.3
	L28_X	69.4		L88_X	74
5	L29_X	107.7		L89_X	17.1
	L30_X	85.9		L90_X	49.2
	L31_X	105.3		L91X	55.7
	L32_X	116.2		L92_X	64.5
	L33_X	90.5	14	L93_X	54.7
	L34_X	109.2		L94_X	23.7
6	L35_X	134.5		L95_X	63
	L36_X	112.2		L96_X	36.7
	L37_X	122.4		L97_X	52.4
	L38_X	89.1		L98_X	57.7
	L39_X	128.2		L99_X	52.1
	L40_X	108.7		L100_X	26
7	L42_X	109.1	15	L101_X	54.2
	L43_X	121.7		L102_X	35.5
	L44_X	80.2		L103_X	54.7
	L45_X	97.2		L104_X	64.4
	L46_X	119.9		L105_X	63.3
8	L47_X	35.7		L106_X	75.3
	L48_48	127.5	16	L107_X	27.7
	L49_X	126.3		L109_X	57.2
	L50_X	133.7		L110_X	37.8
	L51_X	125.8		L111_X	48.4
	L52_X	140.3		L112_X	89.5
9	L53_X	57.7			
	L54_X	17.6			
	L55_X	20.3			
	L56_X	15.2			
	L57_X	78			
	L58_X	68.3			
	L59_X	78.1			
	L60_X	37.2			

Table 6. Identified DLs corresponding to vertical aiming angles and alongwith OAAs for Yuvabharati Football Stadium

Set	Luminaires	Angles	Set	Luminaires	Angles
1	L2_Y	73.69	8	L47_Y	67.06
	L3_Y	56.78	9	L54_Y	75.58
	L4_Y	73.34		L57_Y	61.89
2	L9_Y	63.31		L59_Y	60.11
	L11_Y	72.31	10	L63_Y	59.63
	L12_Y	62.67		L65_Y	70
	L13_Y	64.01		L67_Y	61.02
	L14_Y	69.67	11	L71_Y	76.37
	L16_Y	70.42		L72_Y	61.3

3	L18_Y	56.21		L74_Y	67.36
	L19_Y	72.62	12	L78_Y	73.14
	L20_Y	62.07		L79_Y	64.27
	L22_Y	67.64		L81_Y	72.32
4	L23_Y	56.87		L84_Y	65.49
	L25_Y	72.3	13	L88_Y	69.28
	L27_Y	58.3		L89_Y	71.61
	L28_Y	53.88		L90_Y	66.33
5	L29_Y	61.49		L91_Y	56.6
	L31_Y	72.34		L92_Y	58.45
	L32_Y	70.92	14	L94_Y	72.47
	L33_Y	53.29		L95_Y	66.6
	L34_Y	74.04		L96_Y	71.96
6	L35_Y	66.49		L97_Y	64.52
	L37_Y	58.77		L100_Y	74.53
	L38_Y	56.29	15	L101_Y	71.9
	L39_Y	69.37		L104_Y	61.45
	L40_Y	56.79		L106_Y	64.67
7	L41_Y	56.55	16	L107_Y	64.62
	L42_Y	63.18		L108_Y	55.47
	L43_Y	57.34		L109_Y	63.67
	L44_Y	66.31		L110_Y	56.16
	L45_Y	56.84		L111_Y	64.83
	L46_Y	64.31			

Performance evaluation of t-test based approach

The next phase of approach is the *performance evaluation* [18] of t-test based outdoor sports lighting designing approach. Performance evaluation tests whether the designed system performs satisfactorily for which it is built. The performance evaluation of t-test based approach is carried out through following three steps :

- *First Step* is reforming new set of design solutions for inappropriate designs (interim Design Case 11 to 27) where the aiming angles of the DLs are replaced by OAAs in horizontal & vertical plane and rests of the luminaires kept unaltered.
- *Second Step* is to redesign Yuvabharati Football stadium with this new sets of aiming angles for the inappropriate design cases and redo the calculations to fetch the optical parameters by Calculux.
- *Third Step* is to evaluate whether the six optical parameters (E_H, U_{0H}, U_{1H}, E_V, U_{0V}, U_{1V}) have improved or not for inappropriate designs with respect to initial values. The revised CV values are also compared with the previous results.

The revised and initial values of the optical parameters for the inappropriate design cases are represented in comparative manner through Table 7. The t-test based approach shows significant improvisation of all six optical parameters. In this process of improvising optical parameters, few inappropriate design solutions are also converted to appropriate ones. As an example from Table 7, the redesigned optical parameters for design case no.16 are so improvised now that design case no.16 has been converted from inappropriate to appropriate design according to equation 1.

However, CV is not limited to the outliers or extreme values. It is possible that the field will still have some locations with very high or low illuminance. To some extent, CV is regarded as a good indicator of the overall uniformity. This may be problematic for players, spectators, or cameras. The guidelines suggest to keeps CV under 0.13 for international sporting zone of FIFA Class V Standard [19]. In t-test based approach, the CV is kept well under recommended value for inappropriate designs as indicated in Table 7.

The performance of t-test based outdoor sports lighting designing approach is further analyzed precisely through

$$PI = \left(\frac{(PR)_{\mathrm{Revised}} - (PR)_{\mathrm{Previous}}}{(PR)_{\mathrm{Previous}}} \right) \times 100\% \quad (2)$$

where ‘PI’ stands for ‘*Percentage Improvement*’ and ‘PR’ stands for ‘*Photometric Parameter*’.

Table 8 indicates the quantitative improvement of six optical parameters in terms of ‘PI’. At this point, apart from three odd cases, rests of the parameters have been improvised remarkably by this approach.

Conclusion

Sports lighting designing is a multiple optical parameters optimization approach which is preliminarily dependent on skills of the designer. However this paper illustrates the concept of improvisation of multiple optical parameters through DLs and corresponding OAAs. Hence perticular luminaires of (+X,+Y) quadrant are only to be readjusted with precise horizontal & vertical aiming angles, instead of all the luminaires. The performance evaluation of this technique is also evident from the PI values where all the six optical parameters have been improved. However on the other way, it can also be pointed out that improper aiming of few pertinent luminaires smudge significant loss of artificial light by degrading design quality.

The noteworthy is improvisation of few inappropriate designs to appropriate ones although almost 95% luminaires are getting identified as DLs. Hence in future scope of work, Rough Set Theory based approach can be introduced for further reduction in quantity of DLs.

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Table 7. Comparison of simulated results of multiple optical parameters between Initial design solutions & t-test based design solutions for inappropriate design solutions of Yuvabharati Football Stadium

Design Cases	E_H (Lux)	E_H (Lux) (New)	U_{0H}	U_{0H} (New)	U_{1H}	U_{1H} (New)	E_V (Lux)	E_V (Lux) (New)	U_{0V}	U_{0V} (New)	U_{1V}	U_{1V} (New)	CV	CV (New)
11	2686	**3570**	0.6	**0.7**	0.3	**0.5**	1998	**2786**	0.6	**0.6**	0.4	**0.4**	0.15	**0.03**
12	2623	**3665**	0.4	**0.6**	0.3	**0.4**	1695	**2667**	0.3	**0.5**	0.2	**0.3**	0.08	**0.03**
13	2691	**3105**	0.6	**0.8**	0.4	**0.6**	2134	**2409**	0.5	**0.5**	0.3	**0.4**	0.02	**0.02**
14	2694	**3526**	0.6	**0.6**	0.3	**0.4**	1832	**2510**	0.6	**0.6**	0.3	**0.3**	0.05	**0.03**
15	2674	**3533**	0.4	**0.5**	0.2	**0.3**	1762	**2528**	0.4	**0.6**	0.2	**0.3**	0.07	**0.05**
16	2670	**3453**	0.6	**0.7**	0.4	**0.5**	2395	**2924**	0.5	**0.7**	0.2	**0.5**	0.06	**0.03**
17	2614	**3411**	0.6	**0.7**	0.3	**0.5**	2401	**2810**	0.6	**0.8**	0.4	**0.5**	0.06	**0.03**
18	2687	**3409**	0.6	**0.7**	0.3	**0.5**	2535	**2913**	0.6	**0.7**	0.4	**0.5**	0.09	**0.03**
19	2694	**3285**	0.5	**0.7**	0.4	**0.5**	2764	**2940**	0.5	**0.7**	0.4	**0.5**	0.09	**0.02**
20	2660	**3310**	0.5	**0.6**	0.3	**0.4**	2372	**2793**	0.5	**0.6**	0.3	**0.4**	0.12	**0.04**
21	2658	**3224**	0.5	**0.7**	0.4	**0.5**	2774	**2817**	0.5	**0.7**	0.3	**0.5**	0.03	**0.04**
22	2693	**3433**	0.5	**0.7**	0.3	**0.5**	2225	**2903**	0.5	**0.7**	0.3	**0.5**	0.1	**0.03**
23	2090	**2834**	0.6	**0.7**	0.4	**0.5**	2160	**2288**	0.5	**0.4**	0.3	**0.2**	0.03	**0.02**
24	2650	**3514**	0.5	**0.5**	0.2	**0.3**	2089	**2720**	0.5	**0.6**	0.3	**0.4**	0.1	**0.04**
25	2644	**3574**	0.6	**0.7**	0.3	**0.5**	1978	**2811**	0.5	**0.6**	0.3	**0.4**	0.16	**0.04**
26	2656	**3572**	0.5	**0.8**	0.3	**0.5**	2048	**2850**	0.6	**0.7**	0.3	**0.5**	0.13	**0.07**
27	2660	**3485**	0.4	**0.7**	0.2	**0.6**	2094	**2647**	0.5	**0.5**	0.2	**0.4**	0.11	**0.02**

Table 8. Percentage Improvement (PI) of multiple Optical Parameters by the t-test based solution over Initial Design Solutions for Yuvabharati Football Stadium

Design Cases	% Increase E_H	% Increase U_{0H}	% Increase U_{1H}	% Increase E_V	% Increase U_{0V}	% Increase U_{1V}
11	32.91	9.84	58.06	39.44	7.14	8.57
12	39.73	37.50	60.00	57.35	55.17	73.33
13	15.38	25.40	47.50	12.89	8.33	24.14
14	30.88	-1.72	14.71	37.01	1.79	13.33
15	32.12	37.14	70.00	43.47	29.55	50.00
16	29.33	11.11	33.33	22.09	32.08	87.50
17	30.49	25.45	58.06	17.03	25.81	47.22
18	26.87	11.67	47.06	14.91	6.25	21.95
19	21.94	29.63	51.43	6.37	31.48	28.21
20	24.44	17.02	56.00	17.75	22.00	33.33
21	21.29	20.37	36.11	1.55	30.77	53.33
22	27.48	40.00	73.08	30.47	32.08	85.19
23	35.60	3.13	25.00	5.93	-17.02	-28.13
24	32.60	8.89	29.17	30.21	9.43	38.46
25	35.17	17.74	70.97	42.11	9.43	12.12
26	34.49	46.15	96.00	39.16	11.29	72.41
27	31.02	72.09	139.13	26.41	12.77	45.83