Optimum Selection of a Sustainable Lighting System for a University Class Room in Saudi Arabia

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Abstract
Sustainability assessment is highly critical to the success of a construction project that are to be classified as sustainable building or green buildings, by either using the Leadership in Energy and Environmental Design (LEED) rating tools as in my case or using BRE Environmental Assessment Method (BREEAM) and other rating systems. This paper will involve on developing a decision support system (DSS) following the (LEED®) rating system requirements to; Improved health and well being of building users, Reduced operating costs and energy consumption and lastly to increase the lighting efficiency of the Classroom there by improving the building/student performance. This was carried out by selecting an appropriate energy efficient artificial lighting system for indoor comfort ability, in which case (03) lamps (Incandescent, Compact Fluorescent and LED)were, ran in a simulation program (Dialux 4.10) and also designing for best Natural lighting to improve the performance of University Classroom. The DSS we developed was based on; functional requirement of the space on the aspect of both Natural lighting and also on the users characteristic where by the DF (daylight factor) was used as a parameter and Artificial Lighting where by energy and cost was used as baseline for selection. Base on our criterion for analysis, the LED lamp was found to be more energy efficient and cost effective within a long duration while for the Natural lighting, our design of window gave us a minimum Day Light Factor of 2.2 which was satisfactory according to the LEED requirement.
Keywords: Sustainable lighting, building performance, LEED rating system.

1. Introduction

Buildings fundamentally impact people's lives and health of the planet. The process of designing, developing, and inhabiting the built environment has a profound influence on a community's economy, environment, and quality of life. Sustainability assessment of building's lighting performance is of major importance to building engineers. Sustainability can be defined as development that meets the needs of the present generation without compromising the ability of future generations to meet their needs, (Brundtland Report).Sustainable design includes considering not just how buildings and the surrounding site are constructed, but also where they are constructed. Sustainability assessment using Leadership in Energy and Environmental Design (LEED) is an assessment carried out to establish how environmentally friendly a building development is, based on a variety of aspects including water use, materials used, energy use, ecological impact and internal conditions for occupants. The problems of consumption as to lighting system and indoor environmental improvement have been more common in education building; because having an efficient light, will reduce the cost and improve the performance.

In the course of this paper, we will develop an efficient, effective, and practical decision support system by one of the LEED tools for assessing the sustainability of a design project in order to ;Improved health and well being of building users, Reduced operating costs and energy consumption and lastly to increase the lighting efficiency of the building there by improving the building performance.

2. Methodology

The methodology of this paper is summarized below;

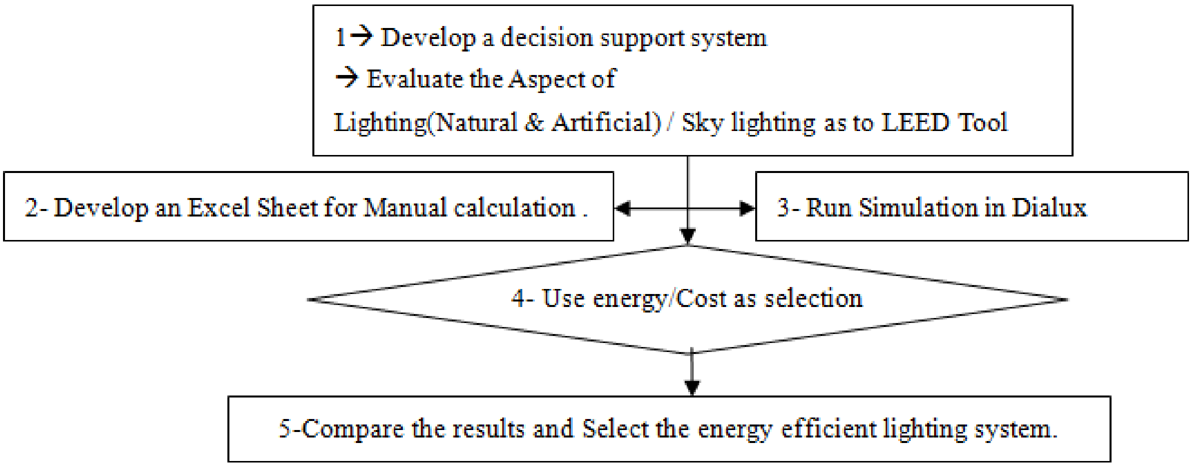


Fig. 1.0 summary of paper's methodology

2.1 Developing DSS (Decision Support System)

Decision support systems have been used in many companies both business and construction to aggrandize on getting optimum business plan, or design process. The aim is to analyze the decision support processes towards energy efficiency and improvement of the Indoor environmental quality in buildings. The main criterion in the decision analysis of buildings is to set a target you aim at reaching.

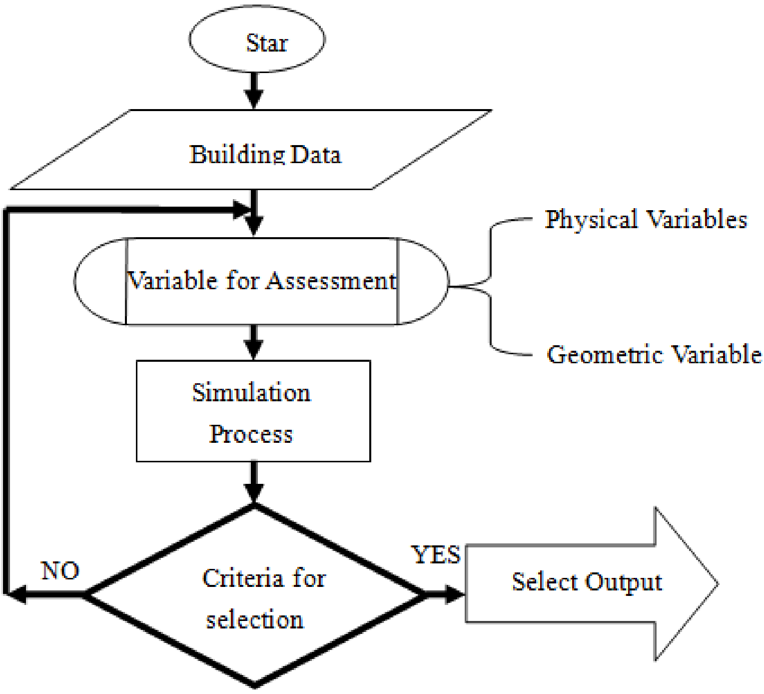


Fig 1.1: Simplified Decision support system

→ **Start:** This is the initial point of the decision system, where we, have to set a fixed or expected output we want to attain. In our case, our Target will be to; get the best lighting system in our indoor environment with energy as baseline.

→ **Building Data:** here we determine first the type of building, the space to be considered for our analysis and what the codes saying about this type of building. Some other data such as; building shape; orientation; building mass; type of glazing and glazing ratio; shading are also considered.

→ **Assessment variable:** We will set Physical variable (Materials, Dimensions and locations) & Geometric Variables such as; Cost and energy consumption.

→ **Simulation process:** This will be done by aid of 'DesignBuilder'& Dialux. After setting criteria for simulation which our case will be between; Incandescent lamps (GL), Compact flourescent lamp (CFL) and LED lighting (LED)

* At the end selecting the best lighting system using energy as a baseline for our analysis.
→Criteria Selection: Our implementation will be on lighting (Natural and Artificial) and the LEED requirement in each case. Under Artificial lighting, the mentioned (03) types of lighting system, were selected based on the availability and use in our case study environment.

2.2 Natural lighting

Day lighting is the practice of placing windows or other openings and reflective surfaces so that during the day natural light provides effective internal lighting. Particular attention is given to day lighting while designing a building when the aim is to maximize visual comfort or to reduce energy use.

→ Code requirement as to LEED for DF (Daylight Factor)

$$\mathbf{DF} = \boldsymbol{G.F} \times \frac{\boldsymbol{window\ Area}}{\boldsymbol{Floor\ Area}} \times \frac{\boldsymbol{T(vis)}}{\boldsymbol{T(\min)}} \times \boldsymbol{H.F}$$

With:
GF = geometry factor
T (vis) = the (manufacturer's) transmittance of the window glazing used.
T (min) = the recommended T (vis) for the window type being evaluated.
HF= A height factor which weights day lighting contribution of glazing above a certain floor height and disallows the contribution below another floor height.
For Side lighting daylight, the code tells us that:

minimum Daylight Factor (DF) of 2%

TABLE 1.0 : LEED™ DAYLIGHT FACTOR EQUATIONS

Window Type	DF=	GF	*	Window Area / Floor Area	*	T(vis) / T(min)	*	HF
Side-lighting (Vision Glazing):	DF =	0.1	*	Window Area / Floor Area	*	T(vis) / 0.4	*	0.8
Side-lighting (Daylight Glazing):	DF =	0.1	*	Window Area / Floor Area	*	T(vis) / 0.7	*	1.4
Top-lighting (Vertical Monitor):	DF =	0.2	*	Window Area / Floor Area	*	T(vis) / 0.4	*	1.0
Top-lighting (Sloped Monitor):	DF =	0.33	*	Window Area / Floor Area	*	T(vis) / 0.4	*	1.0
Top-lighting (Horiz. Skylight):	DF =	0.5	*	Window Area / Floor Area	*	T(vis) / 0.4	*	1.0

→ Code requirement as to LEED for Roof Sky Lighting

The code stipulates that the design of skylight on roof top should cover an area of **3 -6%** the total roof area.
The equation above for DF should suffice for;

$\mathbf{T(min)} \leq \mathbf{0.5\ VLT}$ with **VLT** = visible light transmittance

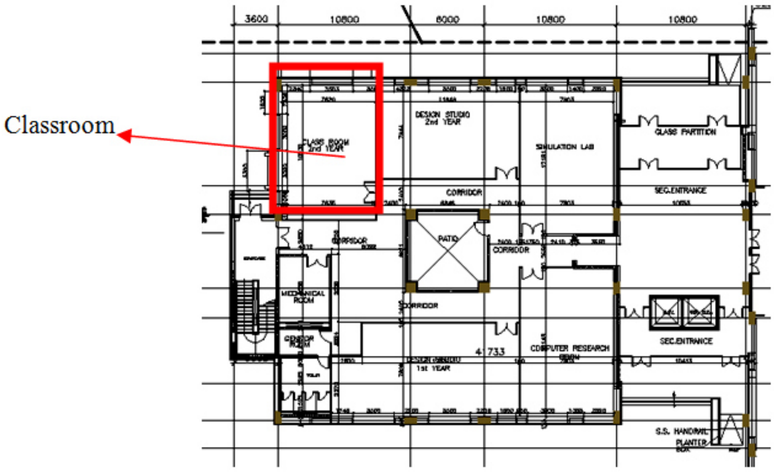


Fig 1.2 Ground Floor plan of the Department of building Engineering, College of Architecture and planning University of Dammam, kingdom of Saudi Arabia

Table 1.1: Measurement of 'Classroom' in study in accordance with table 1.0

Characteristics	Measures
G.F	0.2
H.F	1
T(vis)	0.4
T(min)	0.4
Total floor area	799.5
West window area	13
North window area	49.68
East window area	0
South window area	29.2
Total window area	91.88
Estimation of DF	
DF	0.022984
% of DF	2.23

i- Natural lighting falling on the interior spaces from windows based on the part plan above.

The LEED standard stipulates a min. 75% of daylight;

Since our result gives us DF=2.23%, from LEED standards we needed a min. of 2% for achieving 75% of daylight within the interior spaces thus, the condition is SATISFIED.

We made use of the LEED- NC 2.2 Submittal Template for EQ CREDIT 8.1-8.2- Glazing factor and access to view calculation to check the achievement of 75% of Daylight within the interior spaces with a minimum daylight factor of 2%. It gave us a result of 81.65% > 75%; thus accepted by LEED standards based on our design.

ii- Natural lighting from sky light on roof

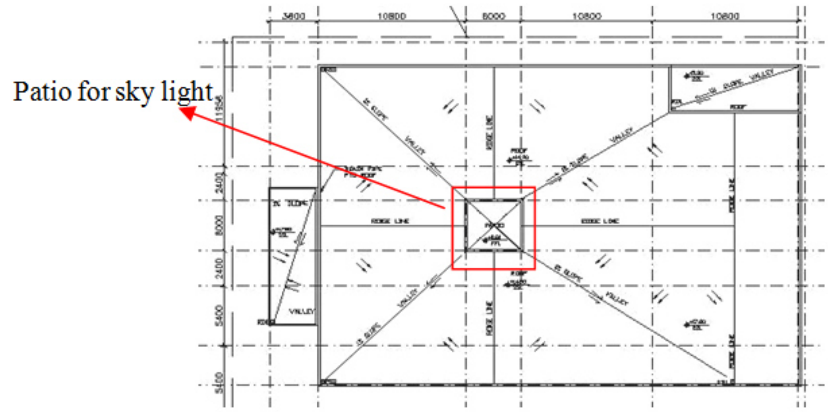


Fig 1.3 Roof plan

Table 1.2 Measurement of the Roof plan

Total floor areas(sq. m)	846
Patio area (sq. m)	46.5
Total Roof Area (sq. m)	799.5
Skylight (%)	5.82

The LEED requirement say; we should achieve 3-6% of skylight as to roof area.

The result gives 5.8% from LEED standard. The requirement needed to be within the range 3 – 6 % of skylight within the interior spaces thus, the condition is SATISFIED.

The LEED aspect of it can be argued that the credit intent (providing a connection between indoor and outdoor spaces through the introduction of natural light) as well as the design intent has been met.

2.3 Artificial lighting

We selected three (03) types of lighting fixtures based on its used and availability within the Kingdom of Saudi Arabia in order to get the energy efficient lighting amongst them. These lighting fixtures were:

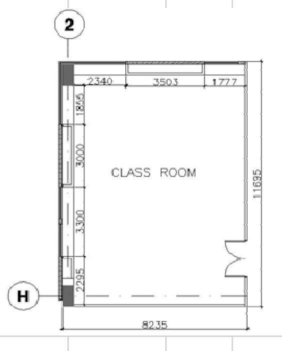
Traditional lighting (Incandescent lamps) ‘GL’, Compact fluorescent lamp(CFL) and Light emitting diode (LED). The analysis was done in two aspect, manual calculation help of excel sheet we developed & by use of simulation program Dialux. The main area for studies was the studio classroom with 300Lux requirement.

3. Results

Table 1.3 Developed 'Excel Sheet' for evaluating lighting scenarios

Scenario 1 - Using Incandescent lamps 'GL'

ARCH PLAN LAYOUT



1- Incandescent lamp			
Characteristic Requirement:-			
1-Illumination level(lux)	300		
2- Lamp Lumen(lm)	1100		
3- Life span(hrs)	800		
4- Power(W)	75		
Space Characteristic :-			
Length(11.7	width(m)	8.3	
1- Area of space(sq.m)	97.11	Wp(m)	0.75
2- Height(m)	2.8	Hm(m)	2.05
3- Standard Colors	70%	50%	30%
4- Maintenance Factor	0.8		
5- Utilizatio Factor	0.6		

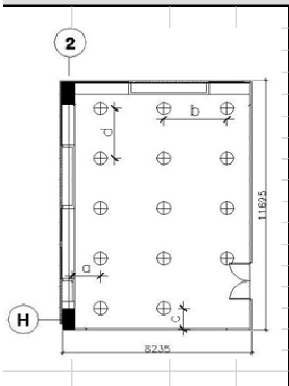
Space Calculations :-			
1- Room Index	1.73411		
2- Uni. Min. Spacing(m)	3.075		
3- Installed Flux	60693.8		
4- Number of Lamps	55.1761	use	56

Layout Calucations :-			
1- min. Spacing(m)	3.075		
a(m)	1.383333333	b(m)	2.766667
c(m)	1.17	d(m)	2.34
use 14luminair = 4lamp/luminair			

Space Demand:-	
1- Total Power(W)	4200
2- Energy (KWH)	3360
3- Cost(SAR)	336

Rate in Saudi:- from 3001 --- 4000KWH ---> **10HALALA/KWH**

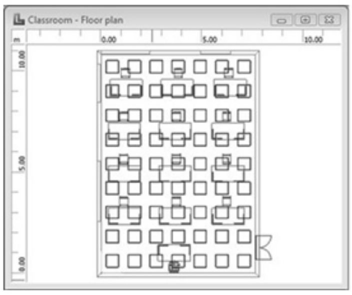
ARCH PLAN LAYOUT



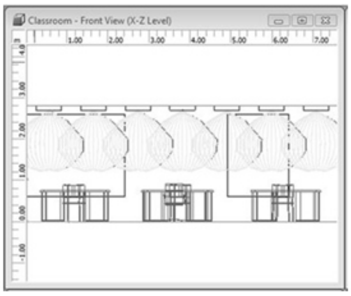
LIFE CYCLE COSTING ASSESSMENT	
Initial cost(SAR)	336
Maintenance /Repair cost(SAR)	60
Discrete Compounding (%)	3
Number (y) of years	5
Replacement cost	40
Salvage (s) Valute (SAR)	288.5346
LCC (SAR)	67.46537

$$S = P(1-i)^Y$$

Fig 1.4-6, shows output result with SCENARIO 1: using Dialux Simulation Software



1- lighting distributions layout



2- lighting pattern

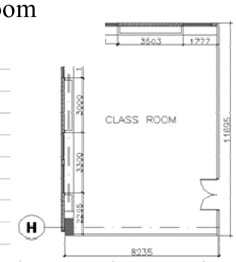
3D view of classroom

The total luminous flux(lm) for scenarios 1 was 69300lm, which was equivalent to 63lamps ' GL'. Dialux gave a total power of 4725W; with a set life span of 800hrs; energy consumption was **3780KWH.**

Table 1.4 Developed 'Excel Sheet' for evaluating lighting scenarios
Scenario 2 - Using Compact Fluorescent lamps 'CFL'

ARCH PLAN LAYOUT

Studio Class Room

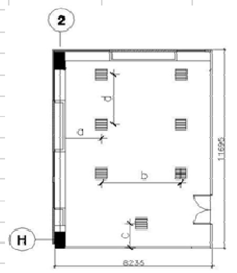


2- Compact Flourescent lamps				
Characteristic Requirement:-				
1-Illumination level(lux)		300		
2- Lamp Lumen(lm)		2400		
3- Life span(hrs)		2000		
4- Power(W)		30		
Space Characteristic :-				
Length(m)	11.7	width(m)	8.3	
1- Area of space(sq.m)		97.11	Wp(m)	0.75
2- Height(m)		2.8	Hm(m)	2.05
3- Standard Colors		70%	50%	30%
4- Maintenance Factor		0.8		
5- Utilizatio Factor		0.6		

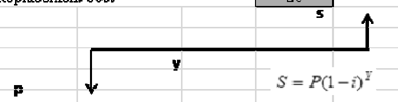
Space Calculations :-			*Layout Calucations :-*			
1- Room Index	1.7341071		1- min. Spacing(m)	3.075		
2- Uni. Min. Spacing	3.075		*a(m)*	*2.075*	*b(m)*	4.15
3- Installed Flux	60693.75		*c(m)*	*1.4625*	*d(m)*	2.925
4- Number of Lamps	25.289063	use	26			
				use7 luminair = 4 lamp/luminair		

Space Demand:-		*Rate in Saudi:-*
1- Total Power(W)	780	from 1001 --- 2000KWH ---> 5HALALA/KWH
2- Energy (KWH)	1560	
3- Cost(SAR)	78	

ARCH PLAN LAYOUT

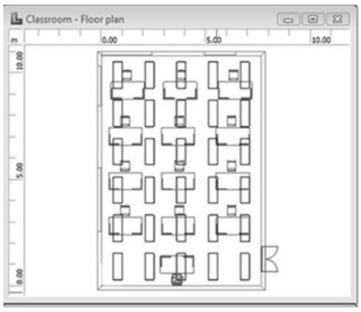


LIFE CYCLE COSTING ASSESSMENT	
Initial cost(SAR)	78
Maintenance /Repair cost(SAR)	60
Discrete Compounding (%)	3
Number (y) of years	5
Replacement cost	20

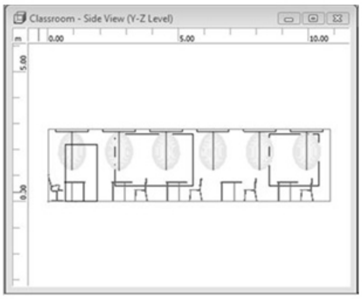


Salvage (s) Valute (SAR)	66.98125
LCC (SAR)	51.01875

Fig 1.7-9, shows output result with SCENARIO 2: using Dialux Simulation Software



1- lighting distributions layout



2- lighting pattern

3D view of classroom

The total luminous flux(lm) for scenarios 2 was 72000lm, which was equivalent to 30lamps ' CFL'. Dialux gave a total power of 900W; with a set life span of 800hrs; energy consumption was **720KW**

Table 1.5 Developed 'Excel Sheet' for evaluating lighting scenarios
Scenario 3 - Using Light Emitting Diode lamps 'LED'

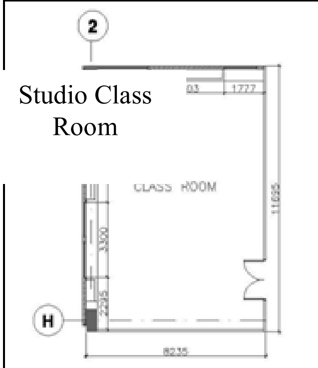
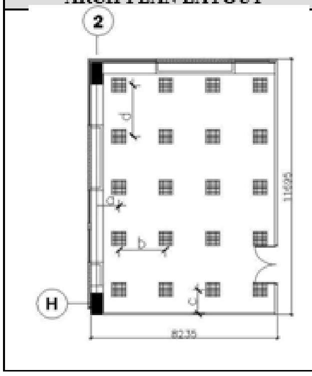
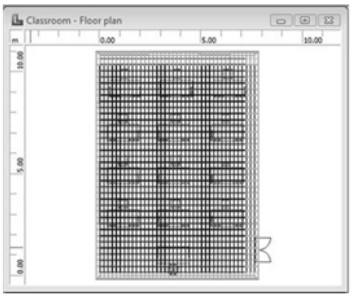
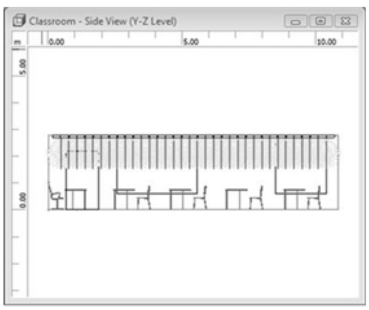
ARCH PLAN LAYOUT							
 Studio Class Room			3- LED lamps				
			Characteristic Requirement:-				
			1-Illumination level(lux)		300		
			2- Lamp Lumen(lm)		80		
			3- Life span(hrs)		6000		
			4- Power(W)		1		
			Space Characteristic :-				
			Length(m)	11.7	width(m)	8.3	
			1- Area of space(sq.m)		97.11	Wp(m)	0.75
			2- Height(m)		2.8	Hm(m)	2.05
			3- Standard Colours		70%	50%	30%
			4- Maintenance Factor		0.8		
			5- Utilization Factor		0.6		
Space Calculations :-				*Layout Calculations :-*			
1- Room Index	1.73411		1- min. Spacing(m)		3.075		
2- Uni. Min. Spacing(m)	3.075		*a(m)*	*1.0375*	*b(m)*	2.075	
3- Installed Flux	60693.8		*c(m)*	*1.17*	*d(m)*	2.34	
4- Number of Lamps	758.672	use	759				
				use20luminair = 40lamp/luminair			
Space Demand:-				*Rate in Saudi:-*			
1- Total Power(W)	758.672	from 1 --- 1000KWH ---> 5HALALA/KWH					
2- Energy (KWH)	4552.03						
3- Cost(SAR)	227.602						
ARCH PLAN LAYOUT			LIFE CYCLE COSTING ASSESSMENT				
			Initial cost(SAR)			227.6	
			Maintenance /Repair cost(SAR)			60	
			Discrete Compounding (%)			3	
			Number (y) of years			5	
			Replacement cost			0	
			p y $S = P(1-i)^Y$				
			Salvage (s) Value (SAR)			195.45	
			LCC (SAR)			92.152	

Fig 1.10-12, shows output result with SCENARIO 3: using Dialux Simulation Software



1- lighting distributions layout



2- lighting pattern

3D view of classroom

The total luminous flux(lm) for scenarios 3 was 63360lm, which was equivalent to 792amps ' LED'. Dialux gave a total power of 792W; with a set life span of 800hrs; energy consumption was **633.6KW**

Table 1.6: Comparison of various scenarios with respect to ' Energy, cost and LCC' from each scenarios' life span(hrs)

Space	Type of lamp	life span(hrs)	Energy(KWH)	Cost(SAR)	LCC(SAR)
Classroom studios	1- Incandescent	800	3360	336	67
	2- CFL	2000	1560	78	51
	3-LED	***6000***	***4552***	***227.6***	***92.2***

The criteria for analysis based on the operation and duration per semester. Considering 10hrs of operation per day with 5days per week and 16 weeks per semester gave us a ***baseline of 800HOURS*** (LIFE SPAN OF INCANDESCENT LAMPS) for our comparison and analysis. Thus:

Space	Type of lamp	Power(KW)	life span(hrs)	Energy(KWH)	Cost(SAR)
Classroom Studio	1- Incandescent	4.2	***800***	3360	336
	2- CFL	0.78		624	31.2
	3-LED	***0.758***		***606***	***30.3***

Table 1.7: comparison of various scenarios from the baseline criteria ' 800hrs'

Based on the Kingdom of Saudi Arabia electricity tariffs depending on the type of project, we converted the energy consumption into cost by multiplying the cost factor corresponding to the energy use.

Slab in kWh	Residential Tariff in Halala/kWh	Commercial Tariff in Halala/kWh	Governmental Tariff in Halala/kWh	Industrial Tariff in Halala/kWh	Agricultural Tariff in Halala/kWh
1 to 1000	5	5	5	12	5
1001 to 2000	5	5	5	12	5
2001 to 3000	10	10	10	12	10
3001 to 4000	10	10	10	12	10
4001 to 5000	12	12	12	12	12
5001 to 6000	12	12	12	12	12
6001 to 7000	15	15	15	12	15
7001 to 8000	20	20	20	12	20
8001 to 9000	22	22	22	12	22
9001 to 10000	24	24	24	12	24
Over 10000	26	26	26	12	26

CHARACTERISTIC			MANUAL CALS		DIALUX	
Space	Requirement From codes	Lamp	Energy(KWh)	Cost(SAR)	Energy(KWh)	Cost(SAR)
Classroom studio	***300Lux*** on the interior space	GL	3360	336	3780	378
		CFL	624	31.2	720	36
		LED	***606***	***30.3***	***633.6***	***31.7***

Table 1.8: comparison of the manual calculations Vs computer simulation; for various scenarios from the baseline criteria ' 800hrs'

The above table 1.8 clearly indicates that the LED lamp is significantly cheap on the basis of energy consumption and cost respectively. To further compare these lamps, we used the 'PAY BACK PERIOD' for the respective lamps in the spaces and we obtained the following results taking into consideration only the manual calculation data with discrete compounding rate of 10% which is used in most economic analysis within the kingdom of Saudi Arabia:-

Table 1.9: Payback period manual evaluation for various scenarios with 10% discrete compounding

MANUAL CALS					
SPACE		**Lamps**	**Energy(KWh)**	**Cost(SAR)**	PP(years)
Classroom	**300LUX**	GL	3360	336	3.9
		CFL	624	31.2	3.9
		LED	606	30.3	3.9

The payback period was seen to be even at **3.9 years** since our cost and consumption was fixed for 800hours of operation during analysis.

4. Discussions an

The results indicated that the LED light is more efficient to be selected to achieve the aim of this paper. There is a close similarity between the manual calculations and the simulated values; which show a good result. The life span and illumination level were kept constant to ease the comparison from the energy and cost point of view; likewise the payback period. Our payback period was also the same for all cases. It was expected to be the same since 5years was used for all.

5. Conclusion

This paper shows that with a DSS with various lamps evolve; for an efficient lighting system in a Classroom design to be sustainable with regards to LEED requirement, the indoor built environment should be furnish with LED light from an artificial lighting point of view. This is with reason being that, LED light is; more efficient, latest lighting technologies, long life spans with more durability and safety. And regarding to Natural light, the window should be design such that they achieve 2.2 Daylight Factor. More works could be done in future, taking into consideration; the cost of the, bulb, lamp-holders, and it's CO_2 emission.

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