Research note

Energy Efficient Lighting System Design for Hospitals Diagnostic and Treatment Room—A Case Study

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Received May 9, 2011, Accepted October 18, 2011

ABSTRACT

Lighting plays an important role in the Hospital Diagnostic and Treatment Room. It shall be environmentally and functionally suitable for three groups of people: patients, hospital professionals and visitors. On the other hand lighting is considered a major consumer of electrical energy and therefore, hospital lighting design should consider the visual performance, visual comfort and energy efficiency. This article discusses the performance of different types of lighting installations used for hospital lighting system design applications: first the visual comfort and second to save energy consumptions in such applications. DIALux 4.8 simulation software is used to study and evaluate the efficient lighting scheme for the hospitals through the use of different types of lamps. Also, visual environment lighting system design procedure is explained. Economics of different lighting scenarios are highlighted.

KEYWORDS: Compact Fluorescent Lamp (CFL), Light Emitting Diode (LED), Light Fitting Cost (LFC), visual performance, visual environment

1. Introduction

In multi function and diverse habitant environment such as hospital treatment rooms, lighting system design plays a major role. Lighting must be suitable for three different categories of people: it should consider the comfort of the patients, the critical visual requirements for hospital staff, the comfort and visual need of the visitors. In addition to these goals, lighting systems can achieve considerable energy cost savings through the careful design of lighting schemes used in such applications. In this article, how the visual comfort and energy efficient lighting system can be designed for hospital lighting applications are highlighted.

The distributions of light within a space substantially influence the perception of the space as well as people within it. Hospital lighting system has two main functions: one is to meet the task requirements in each area of the hospital and the second is to create an environment that is visually satisfying the patients as a good lighting system design can influence human emotions and feelings of well-being.

The works of Patricia Rizzo, Mark Rea and Robert White[1], Hilary Dalke, Jenny Little, Elga Niemann, Nilgun Camgoz, Guillaume Steadman, Sarah Hill, Laura Stott[2)3)], Flynn J. E, Spencer T. J, Martyniuk O, Hendrick C[4)] are the important studies concerning hospital lighting design. Their findings focus only on the visual aspect and human perception of lighting in the hospital lighting design applications.

This article explains the hospital lighting system design procedure using DIALUX 4.8 simulation software as per the international standards. Also, the most appropriate selection of lighting type which is visually and financially viable is highlighted.

2. Requirements of hospital lighting system

i) For the Patients: The physical environment in which a patient receives care affects patient outcomes, patient satisfaction and safety of patients. Patients require a quality lighting environment.

ii) For Staff: From the staff perspective, the visual environment should be conducive to hard work. Studies show that a well-designed working environment can aid recruitment and the retention of staff as well as improving their morale. Another role that lighting can play is to make the environment of the hospital easy for orientation of new staff working in the ward unit. It needs to be visually prominent and provide lighting with maximum efficiency for all users. The immediate environment should be harmonious with variety of luminaires to give the eyes a chance to rest.

iii) For the caretakers of patients: Their needs differ from those of hospital staff and professionals as they may try to sleep during the night rather than try to stay awake.

iv) Visual Discomfort: Studies shows that, there are four situations in which lighting installations may cause visual discomfort. They are:

- visual task difficulty, in which the lighting makes the required information difficult to extract,
- under or over stimulation, in which the visual environment is such that it presents too little or too much information,
- distraction, in which the observer's attention is drawn to objects that do not contain the information being sought,
- perceptual confusion, in which the pattern of illuminance can be confused with the pattern of reflectance in the visual environment.

The most common aspects of lighting that cause visual discomfort are insufficient light, too much variation in illuminance between and across working surfaces, glare, veiling reflections, shadows and flicker. All these aspects are considered in the proposed design.

v) The energy used by lighting system depends on both the power rating of lamps used and the time. Energy efficiency can be achieved by using the most effective and efficient lighting equipment and control that can keep the energy requirement minimum whilst achieving the lighting design objectives.

3. Lighting system design

Luminous intensity, luminance, luminous flux and illuminance are the four basic parameters used in lighting system design. Different types of lamps used in lighting system design with their luminous efficiency and lamp service life is given in Table 1.

The various factors to be considered in the design of lighting system for hospitals are:

i) Natural Illumination: The provision of natural illumination and access to windows is always appreciated by patients and should be considered in the design. Also it is required to limit sun penetration so that thermal and visual discomforts do not occur.

ii) As the common lines of sight for the patient in the hospital is toward the ceiling and the top portion of the opposite walls, design should avoid glare to patients, while still providing good visibility to hospital professionals. A limiting glare index is recommended for each application[6]. Discomfort glare is quantified by the Unified Glare Rating (UGR) derived using equation (1) below.

$$UGR = 8\log_{10}\frac{0.25}{L_b}\sum\frac{L_S^2\,\omega}{p^2} \quad (1)$$

L_b=background luminance (cd/m^2), excluding the contribution of the glare sources.

L_S=luminance of the luminaire (cd/m^2).

ω=solid angle subtended at the observer's eye by the luminaire (steradians).

p=Guth position index.

Typically UGR values ranges from 13 to 30[6]. The lower the value, the less is the discomfort.

iii) Colour rendering requirements: The ability of a light source to render colours of surfaces accurately can be conveniently quantified by The Commission Internationale de l'Eclairage (CIE) general colour rendering index. The colour rendering index is used to compare the colour rendering characteristics of various types of lamp. Eight test colours are illuminated by a reference source, which is a black body radiator of 5000 K correlated colour temperature or 'reconstituted' daylight if more than 5000 K is needed[9]. These eight colours are then illuminated by the test lamp. The average of the colour differences produced between the source and the test lamps provides a measure of the colour rendering properties of the test lamp. The recommended values are given in Table 2[6].

iv) Recommended reflectance values are given Table 3[6].

4. Computer simulation using DIALux 4.8

Computer programs are preferred in architectural

Table 1 Lamp efficiency and service life

Type of Lamp	Lumens per watt	Average lamp life in hours	Color rendering
Incandescent	8–25	1000–2000	100
Fluorescent	60–600	10000–24000	82–95
High Pressure Sodium (HPS)	45–110	12000–24000	83
Low Pressure Sodium (LPS)	80–180	10000–18000	5
Metal halide	60–100	10000–15000	87–93
LED	28–79	25000–100000	40–85

Table 2 Recommended lighting requirements for different areas in a hospital

Area	Illuminance in Lux	Limiting glare index	Minimum colour rendering
General lighting	100	19	80
Waiting rooms	200	22	80
Corridors: during the day	200	22	80
Corridors: at night	50	22	80
Day rooms	200	22	80
Staff office	500	19	80
Staff rooms	300	19	80
Reading lighting	300	19	80
Simple examinations	300	19	80
Examination and Treatment wards	1000	19	80

Table 3 Recommended Reflectance Ranges

Surface	Reflectance
Ceiling	0.7 or higher
Walls	0.5–0.7
Partitions	0.4–0.7
Floor	0.1–0.3
Furniture	0.2–0.5
Window blinds	0.4–0.6

projects to design the lighting systems. Using simulation, concepts can be visually compared during the design phase in order for decisions to be made prior to construction particularly in the lighting calculations due to its ability to provide visual impact of the lighting design for the projects without requiring any real life applications either for all or part of the project such as adding furniture or placing certain interior elements. It also provides an easy way to calculate the required lighting installations and optimize the energy usage.

In this article, DIALux4.8 simulation software is used for the analysis. The accuracy of the result from Dialux software depends on the data provided. Professional lighting designers have been utilizing Dialux software due to its many features such as the Render feature, user-friendliness, the ability to optimize the lighting distribution and quantity which will lead to energy efficient lighting system design. It determines the physically correct numerical values for the proposed system based on CIBSE and IES standards. It has been found in many projects that the results obtained from the simulation with the field measurements are close to real data[10]. For these reasons DIALux4.8 based simulation is proposed in this article. The simulation also helps to check compliance with requirements specified in standards, such as uniformity of illuminance and the recommended lux level as per EN 15193.

A further effective visualization method is false colour rendering diagrams which allow levels to be represented through a colour scale.

Following are the steps to be followed in the lighting system design using DIALux software:

i) Enter project information input.

ii) Enter room geometry: In this step we provide room geometry such as length, width and height, the type of material used for ceiling, walls and ground (which will have impact on the lighting calculation due to different reflection factor associated with each material), lighting loss factor, and the work plane height.

iii) Luminaire selection: Luminaire selection and mounting height will have direct effect on lighting simulation results (Software has electronic library/catalogues).

iv) Placement of luminaire, calculation and visualization of the results: In this step the placement of luminaire will be either manual or automatic, where the designer will have the options to input the desired illuminance. Software will provide the simulation results. One of the major disadvantages of using this software is the standard values provided for many parameters in which case the accuracy is questioned. The design proposed here allows one to input the values as per the standards mentioned in Tables 1–3.

5. Case study

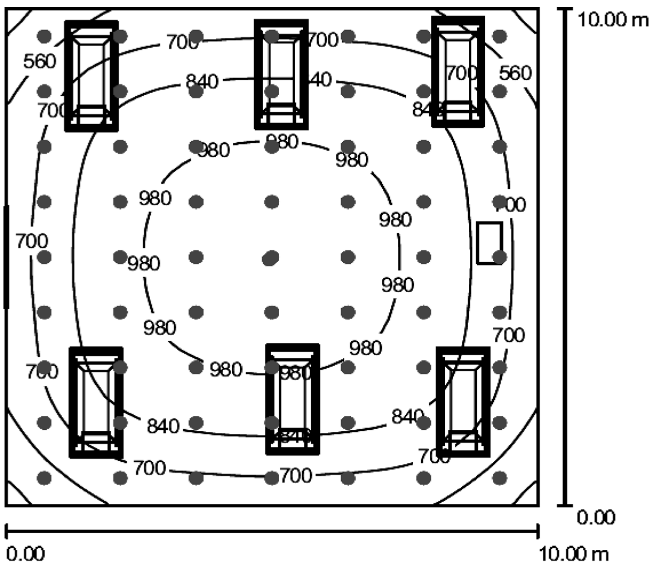
A Hospital Diagnostic and Treatment room in Qatar is selected for the case study. The Diagnostic and Treatment room is a rectangle parallelepiped of 10 m wide, 10 m long and the height of the room is 4 m. This room is divided into small diagnostic rooms separated from each other by sliding curtain wall. The reflection coefficients (supposed diffuse) of the walls are ρ_{wall}=0.5, floor ρ_{wall} =0.2, and the ceiling $\rho_{ceiling}$=0.7[9]. The required Lux level as per Table 2 is 1000 lx. The measurement of required illumination was taken on a work plane that has a height 0.850 m and a grid of 32×32 points were selected. The maintenance factor is assumed as 0.8. The visual comfort shall match the glare index and the colour rendering index is set as per the recommended standards. The price of energy consumption for healthcare applications in Qatar is 0.10 United States Dollars ($) per unit of energy (kWh) consumed. Three lighting scenarios were applied to know the visual comfort through glare effect, color rendering and the power consumption of the diagnostic and treatment room of the hospital through the use of different types of lamps like incandescent, CFL and LED lamps. In the design, the working hours of the hospital is assumed to be 24 h a day, seven days a week. DIALux 4.8 simulation software is used for the case study and the simulation results are shown for each scenario.

6. Scenario 1

The diagnostic and treatment room is illuminated through the use of ERCO product ERCO 46608000 Quintessence Down light 2×TC-TELI26W equipped with ERCO Compact Fluorescent of 2×26 W. Figure 1 shows the lighting distribution values in Lux. Photometric data are shown in Figure 2.

The luminaire layout plan is shown in Figure 3. 3-D colour rendering is shown in Figure 4 which is an accurate representation of the lighting effect. It shows effect of lighting on different area in the room.

False colour rendering is shown in Figure 5 which shows the different area in the room and the possible false colour rendering. A value chart is shown in Figure 6.



Height of Room: 4.000 m, Mounting Height: 4.000 m, Maintenance factor: 0.80 Values in Lux, Scale 1:129

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	814	386	1062	0.474
Floor	20	650	54	1011	0.083
Ceiling	70	160	137	176	0.856
Walls (4)	50	308	112	623	/

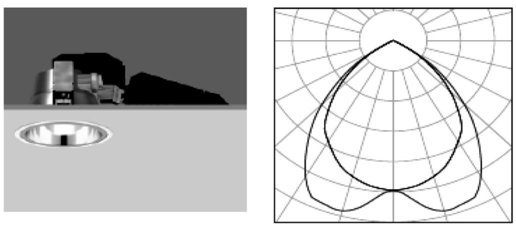
Workplane:
Height: 0.850 m
Grid: 32 x 32 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.386, Ceiling / Working Plane: 0.197.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ [lm]	P [W]
1	127	ERCO 46608000 Quintessence Downlight 2xTC-TELI 26W (1.000)	1800	26.0
		Total:	228600	3302.0

Specific connected load: 33.02 W/m² = 4.06 W/m²/100 lx (Ground area: 100.00 m²)

Figure 1　Lighting distribution values in Lux



127 Pieces ERCO 46608000 Quintessence Downlight 2xTC-TELI 26W
Article No.: 46608000
Luminaire Luminous Flux: 1800 lm
Luminaire Wattage: 26.0 W
Luminaire classification according to CIE: 100
CIE flux code: 71 100 100 100 50
Fitting: 2 x 2xTC-TELI 26W (Correction Factor 1.000).

Figure 2　Photometric data

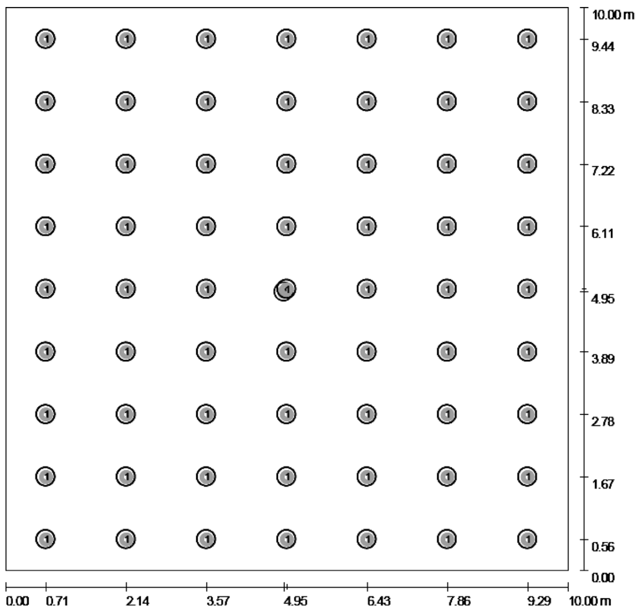


Figure 3　Layout plan

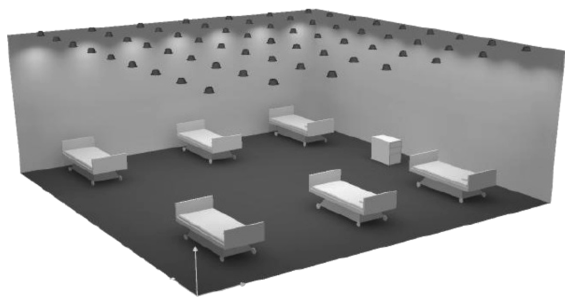


Figure 4　3D rendering

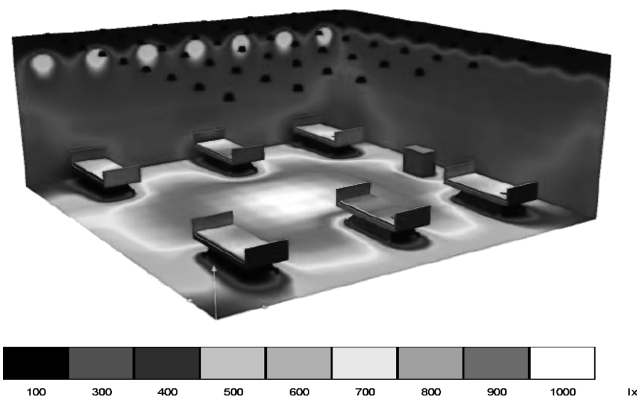


Figure 5　False colour rendering

7. Scenario 2

The diagnostic and treatment room is illuminated through the use of ERCO product ERCO 46815000 Quintessence Down light 1×LED 28 W daylight white, equipped with ERCO LED lamp of 28 W. Figure 7 shows the lighting distribution values in Lux. Photometric data are shown in the Figure 8. Figure 9 is the luminaire layout plan. 3-D colour rendering is shown in Figure 10. False colour rendering scheme is shown in Figure 11 and the value chart for this scenario is shown in Figure 12.

8. Scenario 3

The diagnostic and treatment room is illuminated through the use of ERCO product ERCO 46012000 Quintessence Down light 1×QT12-$_{ax}$100 W equipped

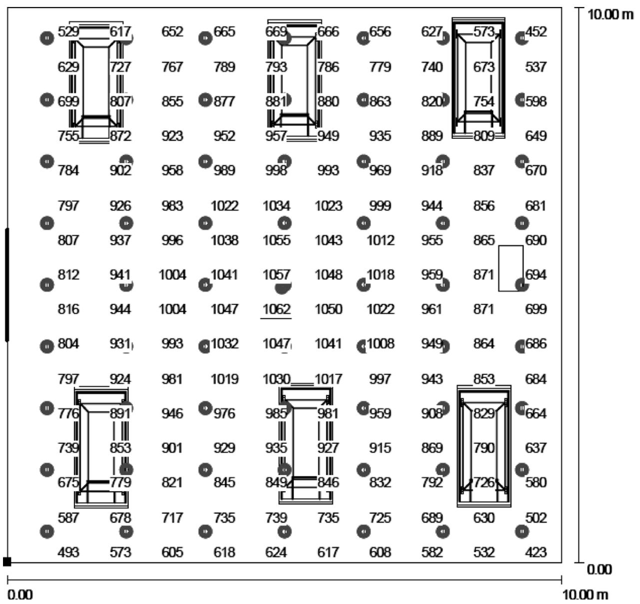
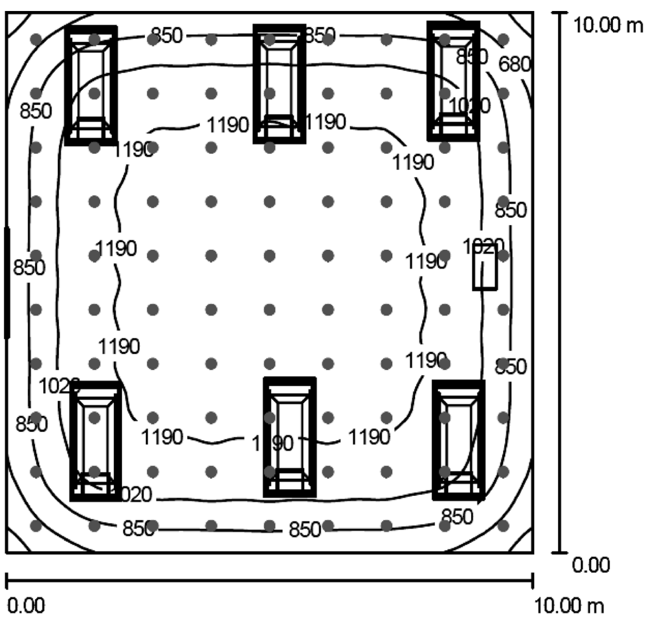


Figure 6 Value chart



Height of Room: 4.000 m, Mounting Height: 4.000 m, Maintenance factor: 0.80 Values in Lux, Scale 1:129

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	1045	436	1237	0.417
Floor	20	853	51	1234	0.060
Ceiling	70	185	147	210	0.794
Walls (4)	50	303	126	457	/

Workplane:
Height: 0.850 m
Grid: 64 x 64 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.294, Ceiling / Working Plane: 0.177.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ [lm]	P [W]
1	90	ERCO 46815000 Quintessence Downlight 1xLED 28W daylight white (1.000)	2160	28.0
		Total:	194400	2520.0

Specific connected load: 25.20 W/m² = 2.41 W/m²/100 lx (Ground area: 100.00 m²)

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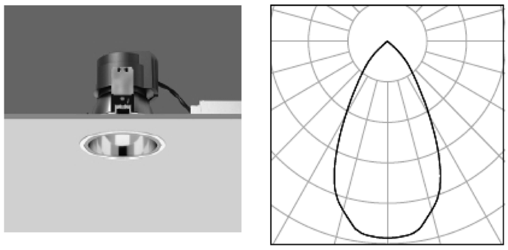
Figure 7 Lighting distribution values in Lux



90 Pieces ERCO 46815000 Quintessence Downlight 1xLED 28W daylight white
Article No.: 46815000
Luminaire Luminous Flux: 2160 lm
Luminaire Wattage: 28.0 W
Luminaire classification according to CIE: 100
CIE flux code: 92 100 100 100 71
Fitting: 1 x LED 28W daylight white (Correction Factor 1.000).

Figure 8 Photometric data

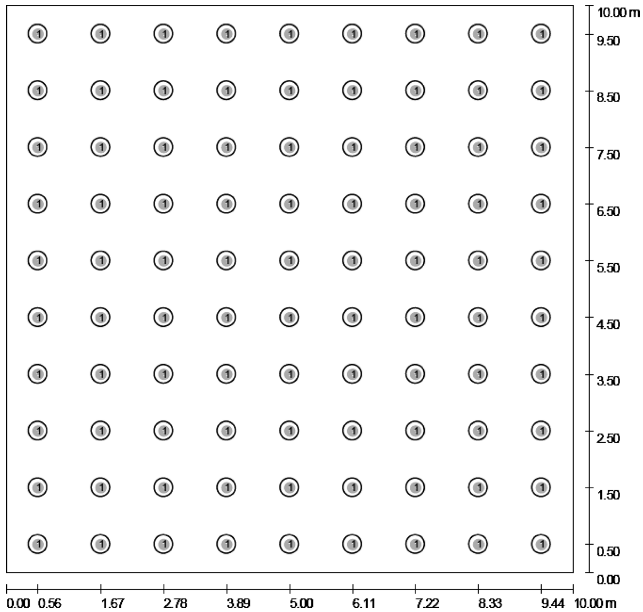


Figure 9 Layout plan

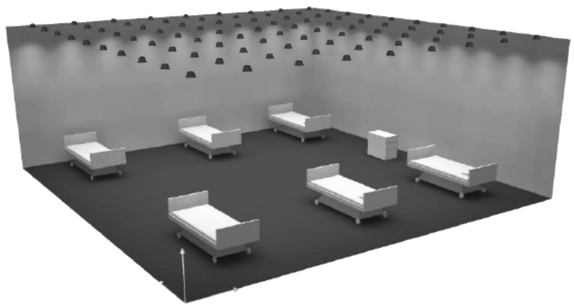


Figure 10 3D rendering

with ERCO Incandescent lamp of 100 W. Figure 13 shows the lighting distribution values in Lux. Photometric data are shown in the Figure 14.

Figure 15 is the luminaire layout plan.

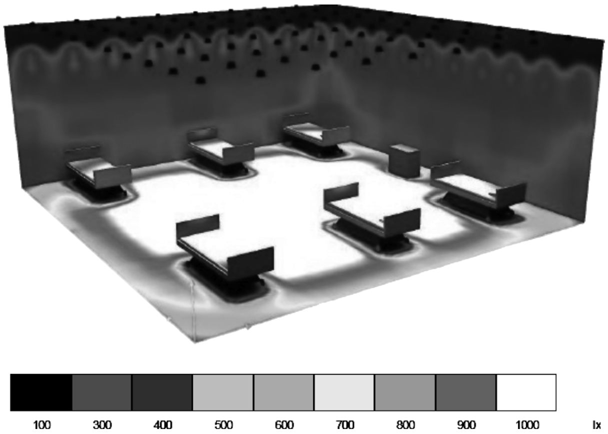


Figure 11 False colour rendering

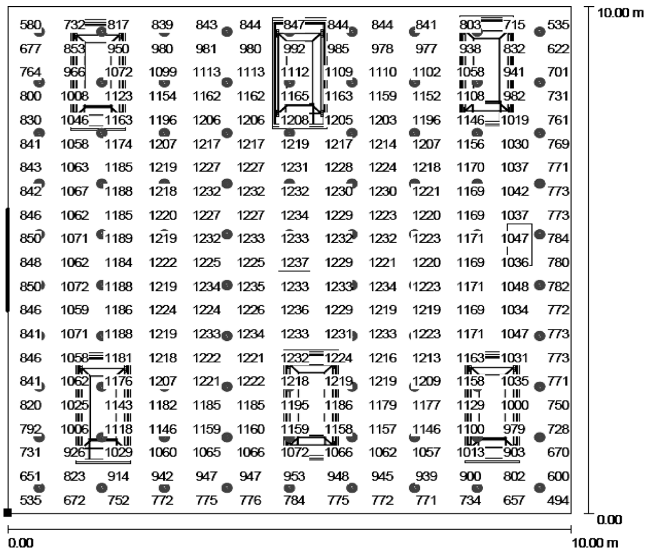
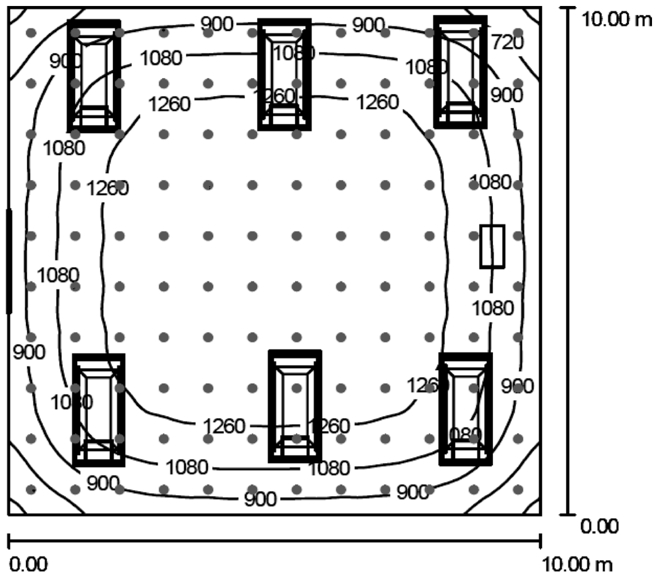


Figure 12 Value chart



Height of Room: 4.000 m, Mounting Height: 4.000 m, Maintenance factor: 0.80

Values in Lux, Scale 1:129

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	1134	511	1406	0.451
Floor	20	914	65	1382	0.072
Ceiling	70	216	180	250	0.834
Walls (4)	50	386	142	678	/

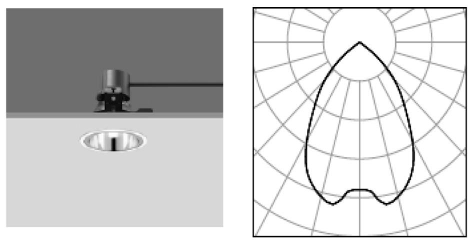
Workplane:
Height: 0.850 m
Grid: 64 x 64 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.348, Ceiling / Working Plane: 0.191.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ [lm]	P [W]
1	120	ERCO 46012000 Quintessence Downlight 1xQT12-ax 100W (1.000)	2200	100.0
		Total:	264000	12000.0

Specific connected load: 120.00 W/m² = 10.59 W/m²/100 lx (Ground area: 100.00 m²)

Figure 13 Lighting distribution values in Lux



120 Pieces ERCO 46012000 Quintessence Downlight 1xQT12-ax 100W
Article No.: 46012000
Luminaire Luminous Flux: 2200 lm
Luminaire Wattage: 100.0 W
Luminaire classification according to CIE: 100
CIE flux code: 83 100 100 100 58
Fitting: 1 x QT12-ax 100W (Correction Factor 1.000).

Figure 14 Photometric data

3-D colour rendering is shown in the Figure 16. False colour rendering is shown in Figure 17 and the value chart is shown in Figure 18.

9. Results and conclusions

There is no doubt that lighting is an important factor for the hospital staff, patients and to the utilities provider. It helps hospital staff in performing their work and it also helps patients in their journey to speedy recovery. Therefore visual comfort and energy use shall be considered in determining the right type of light in the hospital lighting system design.

Visual discomfort represented by some lighting features such as glare, hum, and flicker can cause health problems. Their negative effects such as straining the eyes, headaches, eye irritation can lead to fatigue and attention deficit. Among the three light fixtures which are studied in this article, only LED lighting has the ability to eliminate these ailments.

From visual comfort perspectives, LED can be considered the best choice in hospital lighting system design as the main cause of visual discomfort is not associated with it. Also, since DC voltage is used to power LED lights, it doesn't produce or cause flickering. Discomfort glare can be eliminated for the LED lighting

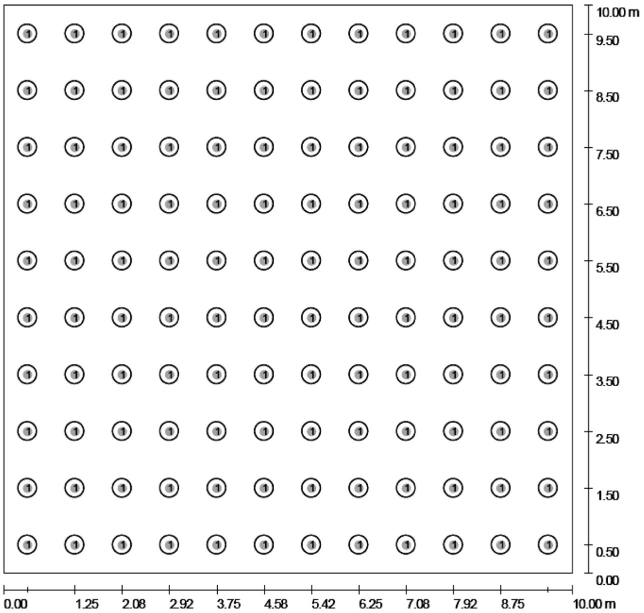


Figure 15 Layout plan

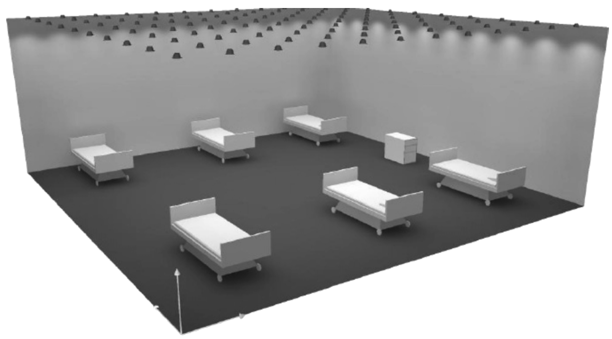


Figure 16 3D rendering

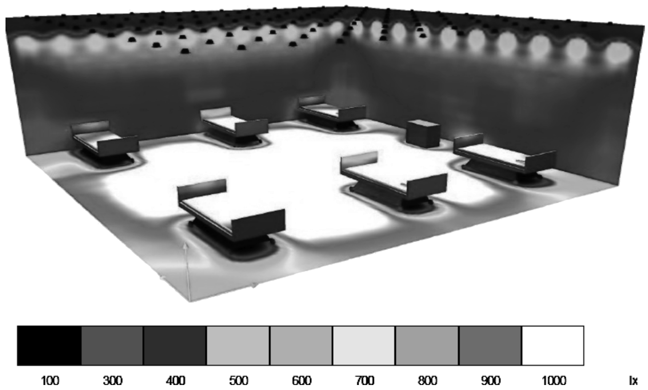


Figure 17 False colour rendering

through the wide selection of the LED lamps within the recommended index set by the standards. Additionally, since LED lighting system use no filaments or extraneous moving parts, the humming sound associated with fluorescent lights is also eliminated.

The design of lighting systems using manual design procedure is very lengthy as there are many variables and parameters to be taken into account and if not selected properly may lead to error which can be realized only after its implementation in the actual site.

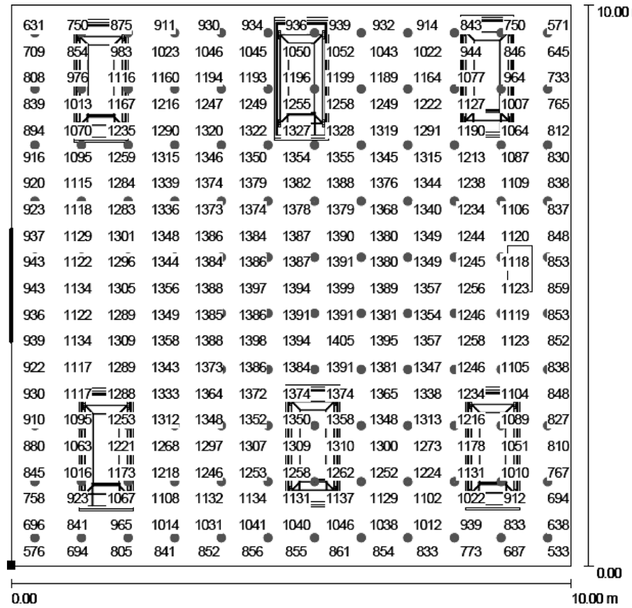


Figure 18 Value chart

Table 4 Simulation Results Summary

Type	No of lamp	Power consumed P (W)	Power density (W/m^2)	Unit price ($)	Light Fitting Cost (LFC) in $
CFL	127	6604	66.04	400	50800
LED	90	2520	25.20	1000	90000
Incandescent lamp	120	12000	120	225	27000

Professional lighting simulation programs presented in this article provide accurate results with option to optimize and visualize the impact of different lighting design scenarios. Manual verification of the results shows that the accuracy of the proposed algorithm is high.

The simulation results of the lighting system design are summarized in Table 4.

In scenario 1, CFLs are utilized and the design is requiring 127 light fittings to give 1000 lx levels. There is 45% power saving compared to the design with incandescent lamps. The power density is 66.04 W/m^2 which is higher than the recommended. In an efficient lighting design, the recommended lighting power density for hospital lighting shall be in the range of 25 W/m^2 [14]. Therefore this is not the best lighting system design from the energy density perspective.

In scenario 2, LED lamps are introduced and there is 79% power saving compared to the design using incandescent lamps. Also the power density is 25.2 W/m^2

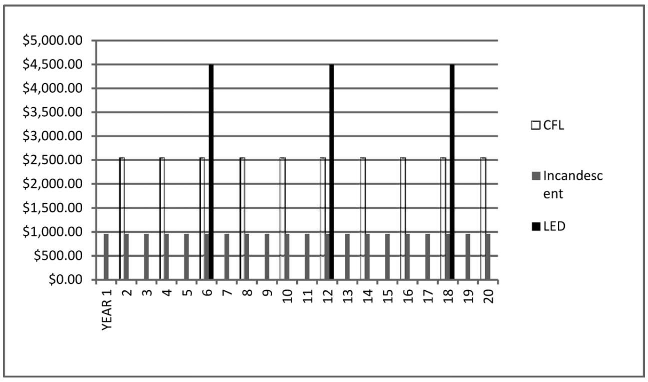


Figure 19 Replacement cost of lamps

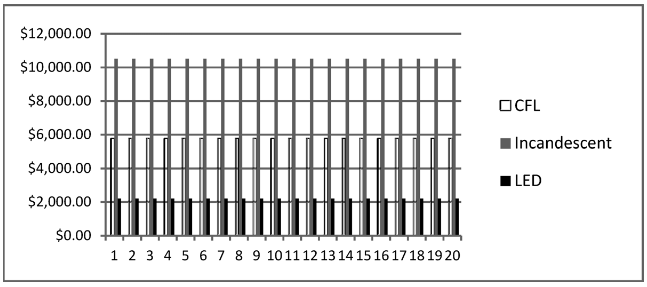


Figure 20 Consumption cost of various lamps

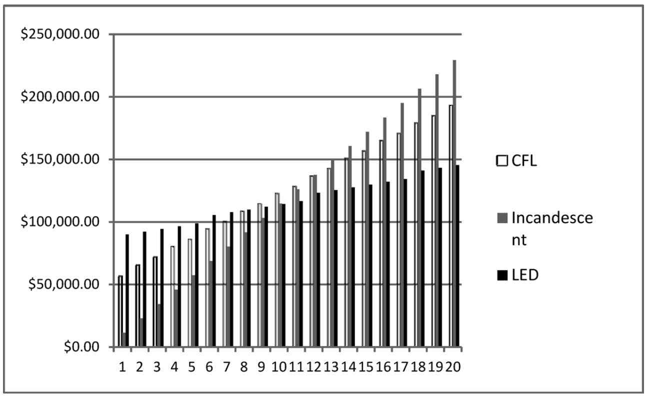


Figure 21 Whole life cycle cost analysis

which is close to the recommended standards.

In scenario 3, incandescent lamps are used and the power consumption is 12 kW to produce 1000 lx levels. Also, the power density is 120 W/m^2 which is very high and exceeds the recommended standards.

Thus, LED lamps are best suited for the energy efficient lighting system design in the hospital lighting system applications.

Life cycle cost analysis is carried out assuming that the only part of the lamp fittings which requires replacement is the lamps:
100 W if incandescent lamps with the cost of $1 per lamp, 1000 h of operating life and 120 lamp fittings.
2×26 W if CFLs are used with the cost of $10 each, 10000 h of operating life and 127 light fittings.
28 W if LED lamps are used with the cost of $50 each, 50000 h of operating life and 90 light fittings. The result shows that over twenty years of operation, the design using LED lamps will have lesser lamp replacement cost (LRC) despite its high initial cost as compared to the design using incandescent lamps and CFLs. Lamp replacement cost is shown in the Figure 19 and the energy consumption cost is compared and is shown in Figure 20.

The whole life-cycle (WLC) cost is calculated using equation (2) and the result is shown in the Figure 21.

$$WLC = LFC + LRC + X \tag{2}$$

X=consumption cost in $

The result shows that, pay-back period is around seven years with the design using LED lamps over incandescent lamps and nine years with the design using LED over CFL. Hence, the design using LED is better choice as far as the financial judgment is concerned despite its high initial cost.

At present the price of LED bulb is considerably higher than the price of other light bulbs. In future, we believe that the price of LED bulbs will dramatically decline due to: Awareness of the energy efficient lighting using LED lamps becoming familiar with the people; there is strong push from LEED certified lighting product distributors and Green Building initiatives coming from government agencies and industrial sectors advocating the use of LED lamps in building lighting projects.

However, our experience says that the energy price will always play a critical role in determining the future of advancement in energy saving technology.

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