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A New Trend for Indoor Lighting Design Based on A Hybrid Methodology

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Abstract

Most power system planners are interested in the savings of electrical power consumption. Various references demonstrate that the highest consumed power is by the lighting systems standing around 19% of worldwide energy consumption. This article presents novel design methodology leading to maximizing revenue due to savings in electrical energy consumption through energy efficient installations. This hybrid methodology is built by combining benefits of the two traditional lighting design methods (lumen and specific connected load methods). This results in developing a new mathematical and applicable model with many advantages such as: high accuracy, fast calculations and most economical design. This proposed methodology is supported by MATLAB® package to shorten the long time consumed by conventional procedures and simplify the complex manual calculations. The hybrid method verifies its effectiveness and efficiency for achieving the maximum savings in energies and costs through the detailed discussion of case studies. A comparison with traditional designs will be introduced to ensure the achieved savings in costs leading to high quality and efficiency of power systems. By practically applying this new hybrid technique particularly for the Egyptian residential and commercial sectors, the system is expected to achieve a huge savings in consumed lighting energies and costs, which can reach 4489.433415 million E£ "≈ 280.5895 million $ "USD"" each year. The presented case studies give accurate and promising results for the proposed methodology as a new trend in energy and money saving system, which is verified by implementing two case studies and comparing with results from DIALux program. The results of the proposed methodology are very effective compared with that of conventional methods for marked benchmarking features and validation. MATLAB® simulation results of the proposed technique are implemented to verify its feasibility for any activity.

1. Introduction

Improving efficiency and reducing energy consumption are essential for sustainable grids [1]. The building sector is considered as one of the most sectors that consumes energy standing about 30-32% from the total energy productions, where the lighting loads consume between 5% to 20% in residential loads and up to 30% in commercial buildings [2-4]. For instance, in Europe, it represents about 14% of all energy consumption, while this ratio is around 19% of worldwide energy consumption. In special loading types, for example the retail sector, it may reach up to 80% of the energy used [2-4]. Therefore, many researchers are seemingly interested in decreasing the consumed power in lighting sections with various methods/algorithms. The study in [5] gave a sample of combined saved energy of light sources used in Japanese common squid jigging fishery. Papers [6-12] presented various controlled lighting systems to produce the required illuminance according to the human occupancy, reference to the place activity or by the vehicles traffic density in the street [10] and illumination sensors [11]. Paper [13] showed the reduction in electrical power consumption for the commercial buildings by some modifications of the installations and used materials. Paper [14] presented the design and implementation of a prototype scaled model, which can switch the power to street lamps between solar and grid supply with economic manner.

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Nomenclature

Abbreviations		*w*	*Room width, m*
CIBSE	*Chartered institution of building services*	*N*	*Number of luminaires/fixture*
CIE	*International commission on illumination*	*n*	*Number of lamps/luminaire*
ILP	*Institution of lighting professionals*	*F*	*Light output ratio*
DIN	*German norms: deutsches institute fur normung*	*Kr*	*Room index*
NFPA 101	*National fire protection association "life safety standard"*	*Ht*	*Total room high, m*
		H_s	*Luminaire suspension distance from ceiling, m*
IESNA	*Illuminating Engineering Society of North America*	H_m	*Net used high, m*
BS	*British Standard*	*ρc*	*Ceiling reflection factor*
EN	*European engineering standards*	*ρw*	*Wall reflection factor*
IEC	*International electrotechnical commission*	*ρf*	*Floor reflection factor*
ISO	*International organization for standardization*	*Φi*	*Luminous luminaire flux under normal condition*
EGA	*Enhanced genetic algorithm*	*Φ*	*Luminous flux of the lamp "luminaire"*
DLCS	*Daylight-linked control systems*	*K*	*Light loss factor*
IoT	*Internet of things*	*Pc*	*Total fixtures luminaires connected loads, (W/m2. 100 lx)*
BZ	*British zonal*		
ZVEI	*German electrical engineering and industrial federation*	*PL*	*Luminaire connected power, W*
		f	*Correction factor*
Revit BIM	*Program for architecture design*	*CT*	*Total fixed costs, E£ or $*
		CF	*Fixed luminaire/lamp cost, E£ or $*
Symbols and codes		*CR*	*Running costs, E£ or $*
I	*Incandescent lamp*	*tb*	*Light source lifetimes, h*
PAR	*Parabolic reflector*	*ta*	*Light source service life*
IC	*Compact tubes*	*R*	*Maintenance cost/year, E£ or $*
A	*General service lamp "incandescent lamps"*	*a*	*Tariff, E£ or $/kWh*
QR	*Halogen reflector lamp*	*TQ*	*Halogen lamp (tubular form)*
QT	*Halogen lamp (tubular form)*	N_A	*The numbers of fixtures of a light source*
T	*Fluorescent lamp*	$N_{(QT)}$	*The numbers of fixtures of QT light source*
TC	*Compact fluorescent lamp*	N_{TC}	*The numbers of fixtures of TC light source*
LST	*Low-pressure sodium lamp*	*Nj*	*The numbers of fixtures of light source named Nj*
E	*Nominal illumination, lx*	*Si*	*The matrix number of combined light sources*
MF	*Maintenance factor*	*C*	*Capital cost of one light source fixture, E£ or $*
RSMF	*Room surface maintenance factor*	*C1*	*Cost of light source fixture lamp/s, E£ or $*
LLMF	*Lamp lumen maintenance factor*	N_i	*Substituted numbers of each light source in E calculations, (i.e. NA =10, N_i ranges from 1,2, 3…10)*
LSF	*Lamp survival factor*		
LMF	*Lighting maintenance factor*		
Uf	*Utilance/coefficient of utilization "utilization factor"*	α_j	*Coefficient factor*
		Ei	*Total illumination value with combinations of various light sources*
L	*Room length, m*		

Authors in [15] introduced their proposed saving system and introduce more than 22 power-saved researches, which show how to control the consumed power used especially in the lighting loads by numerous methods. On other side, IoT is also used in many applications. In [16], a micro-IoT architecture is used for LED lighting and diming control in smart homes and in [17], it is used in street lighting aided by video vehicle detection and light-dependent resistor (LDR) to control lighting on the streets to increase the safety and power saving. In [18], sensor-triggered control strategies are used to save consumption lighting power depending on the acceptance of seventeen (17) participants on the dimming fading time through their experiences and experiments. The research in [19] indicated a greater circadian stimulus and power saving by desktop overhead rather than overhead luminaires of ceiling lighting systems. In [20], the study focused on the effectiveness of using LED light sources on the greenhouse crops of tomatoes by energy combination, which can increase the yield by 12.3% and save consumed power by 30.1% instead of other threshold strategies. Authors in [21] presented the potential energy saving, from 20% to 30%, on the energy demand for lighting for an office room and a classroom by "DLCSs and occupancy off control" rather than manual ones. Other important paper [22], gave the current trends and the future directions with highlight on implementing of the hybrid: intelligent lighting control systems with intelligent control techniques especially in the commercial buildings. Authors in [23] introduced combined efficient energy analysis software with DIALux software as an intelligent energy management system. It is examined for high energy savings in metro stations in china, but without high efficiencies.

2. Overview of lighting design

Lighting is an art as well as a science and it needs more interest regarding the lighting design. The appropriate used lighting design method depends on many important parameters and the design engineering experiences [24,25]. There are many interested institutions, commission, societies and standards for lighting design, which can be used by lighting designer according to regions and needs, such as CIBSE, CIE, ILP, DIN, NFPA 101, IESNA, Engineers Lighting Code UK norms, BS, EN, IEC and ISO [25-28]. There are some researches interested in lighting design methods and its effective parameters. One of these methods is designing an appropriate lighting system by using the natural light and energy efficient luminaires [24,29]. Research [30] tried to reach the optimal selection of power saving light sources, where its design takes into account various surrounding conditions. Papers [31,32] showed the influences of lighting on the people's productivity and performance especially students' learning performance. For instant, paper [32] took the colour temperatures as an effective performance parameter, while others studies, i.e., [33,34], focused on the design and measurements of lighting illuminance for visual and un-visual systems to give an attention to circadian regulation, which affects sleep and mood with some suggestions for lighting designers. On the other side, the authors in [35] introduced comparisons of two outdoor lighting methods to select the best economic one for street lighting. Paper [36] explained how lighting designers are interested in the energy efficiency of light sources such as LED types added to the visual performance. Paper [37] introduced LED with high colour quality to improve the appearance of illuminated objects with some modifications on various colours band to get the required rendering index. The research in [38] analysed the influence of the luminance uniformity and spectral power distribution of LED luminaires on discomfort glare by two generic models. Paper [39] discussed the light level and visual comfort by taking into consideration glare index calculations. In [40], another study investigated the appropriate seating position and view direction in a west-facing office depending on two visual comfort objectives: daylight and glare index. Paper [41] indicated, in detail, the updating for future research works in the lighting systems from many aspects viewpoints: measurements, designs and health. Paper [42] focused on the state and conditions surrounding the lighting system to give the optimal selections, where it makes the measuring and correction quality actions between the selected lighting quality metrics derived from the spectrum and a representative set of interior light source spectra. Research [43] motivated the researchers to discuss the effective use of combination of LED products to reduce insect attraction. Authors in [4,44] tried to increase natural light availability, where authors of [4] supposed six different configurations of an internal/external light shelf and they advise the most two efficient models. Authors of [45] gave advisements to lighting designers, road authorities, etc. to use significance indicators (e.g. new part of EN13201-5) in the initial stage of lighting design and for evaluation a criteria, which can increase energy savings. Paper [46] indicated the effects of low/high illumination on the human safety and it introduced stair LED safety model. Authors in [47] introduced fixed and more energy efficiency illumination for interior lighting spaces by mixing the daylight (Fresnel lens) and LED lamp.

2.1. The aims of the proposed paper

1. Developing the mathematical construction of the hybrid proposed method,
2. Giving the proposed mathematical model with clear effective factors calculations, unlike other programs such as: Dialux, Relux, etc. that give the design without indicating these factors,
3. Creating multi-designs from individual designs, and highlights the saved energy and money through case studies,
4. Evaluating the energy savings effectiveness on increasing the quality of power system,
5. Giving accurate, easy and fast open-code designing program for the lighting designers,

2.2. Lighting design advantages

The lighting design "good lighting system" plays an important role in safeguarding health for the persons using these systems. Therefore, it should satisfy many requirements, such as [29,48-52]:

- Regarding general features, it should fulfil illumination level" E", uniform distribution, glare limitation, etc.
- Regarding new and advanced quality criteria, it should achieve energy efficiency, possibility of simple control and regulation, etc.
- Regarding energy consumption, it should realize energy conservation, use of daylight, detector implementation, saving lamps, etc.

2.3. Lighting definitions

There are some important definitions, such as: lighting, luminous flux, glare, colour rendering classes, etc. [24,27,29,48,49,53-56]. This study is interested in the indoor lighting design, where the appropriate light sources types, symbols, and utilizations are summarized in the Nomenclature and more details are found in [48,49,54,57]. The recommended light levels "E, lx" and their accompanied light lamps are given in Table 1 [24,29,48,49,53-61]. Some of these light source samples are used in the case studies [54].

Regarding Table 1, the following remarks can be summarized: Table 1 explains the activity spaces illuminance "E" levels and the corresponding light sources, the complete design "accurate design" should take into consideration the illuminance according to: task area, surrounding area and immediate vicinity of the task area [48-49], and reference [54] gives samples of light source types with their main data.

Table 1. Samples of recommended lighting indoor illuminance and light sources symbols [24,29,53-61].

Space/activity	Recommended illuminance, E "lx"	Light source
Office	300	T, TC
Team office	500	T
Open plan office	750	T, TC
Technical drawing office	750	T, TC
Data processing	500	T, TC
Canteen kitchen	500	T
:	:	:
Laboratory	500	T, TC
Concert platform	750	PAR, R, QT
Meeting room	300	A, QT, TC

2.4. Lighting design methods

There are three methods to accomplish the practical lighting design calculations, which depend on multi-effected variables and parameters "getting from standard references or manufacturers, e.g. [24,29,48,49,53-63]".

2.4.1. Utilization factor "British Zonal (BZ)"/Lumen method

The utilization factor method, the common method, estimates the dimensioning (the total numbers of luminaries and their distribution through the activity space including length and width) of a lighting installation. It helps the design engineer to decide the number of luminaires "N" and, accordingly, the fixtures on the working plane. This method gives an average illuminance over the overall space, which represents the common method in most design programs. The illumination level "E" can be calculated as follows [24,25,53-61,64-67]:

$$E = \frac{\Phi.N.n.Uf.K.F}{L.W}, lux \quad (1)$$

The terms (K.F) may be replaced by MF "maintenance factor" [37,42] that can be calculated from:

$$MF = LLMF.LSF.LMF.RSMF \quad (2)$$

Table 2 gives various maintenance factors according to room classifications.

2.4.1.1. Factors determination

1. The light output ratio, F is the ratio of "Φi" under normal conditions to "Φ", which depends on the lamp type [54].

$$F = \frac{\Phi i}{\Phi} \quad (3)$$

2. Utilance/coefficient of utilization, Uf, can be calculated after deciding the following factors:

- Room index "Kr", which describes the influence of the room geometry on the utilance [25,61];

$$k_r = \frac{L.W}{H_m.(L+W)} \quad (4)$$

The net used height H_m;

$$H_m = H_t - H_s - H, m \quad (5)$$

- The room reflection factors; ρc, ρw and ρf decided according to their colours [54].

By using k_r,ρc,ρw and ρf, "Uf" can be decided from the luminaire/lamp datasheet Table "light sources/lamps Uf table" [54].

3. The light loss factor "K" indicates the reduction in lighting lamp performance [54].

Table 2. MF for various environmental [61].

Room classification	Lamp maintenance factor (time-schedule cleaned lamps)	Lamp maintenance factor (not time-scheduled cleaned lamps)	Total maintenance factor
Very clean	0.9	0.85	0.85-0.9
Clean	0.9	0.9	0.8
Average	0.9	0.8	0.7
Dirty	0.9	0.7	0.6

4. The maintenance factor "MF", which can be decided according to room classifications and lamp/luminaire condition [61,65].

2.4.2. Point-by-point method

This method is programming dependent, which can predict direct illuminance at each point on a plane "using measured data of luminous intensity distribution of a source or a luminaire". It depends mainly on the inverse square law and cosine law. Computer software, e.g., Revit BIM, can be used to perform numerical point-by-point calculations and sketch this distribution [54,61,67].

2.4.3. Specific connected load method

This method is connected-load dependent. The illuminance of luminaire, with its average consumed power, and the appropriate illumination "E" can be decided as follows [24,53,54,56]:

$$E = \frac{P_L.100.N.f}{P_C.L.W}, lx \quad (6)$$

$$N = \frac{E.P_C.L.W}{P_L.100.f} \quad (7)$$

2.4.3.1. Factors determination

Total luminaires connected loads, P_c, can be determined by the manufactures tables or by the standard references as shown in Table 3 [54].

The correction factor "f"; is determined according to H_t, ρc, ρw, and ρf as illustrated in Table 4 [54].

2.4.4. Lighting costs

The lighting costs are very important to decide the efficient designs, where the costs comprise: the fixed cost including

Table 3. Determined "Pc" for direct luminaires [54].

Lamp type	Pc (W/m². 100 lx)
A	12
QI	10
T	3
Tc	4
HME	5
HIT	4

Table 4. Correction factor "f" [54].

H_t, m	A (m²)	ρc, ρw and ρf		
		0.7, 0.5, 0.2	0.7, 0.5, 0.2	0.7, 0.5, 0.2
≤ 3	20	0.75	0.65	0.60
	50	0.90	0.80	0.75
	≥ 100	1.00	0.90	0.85
3-5	20	0.55	0.45	0.40
	50	0.75	0.65	0.60
	≥ 100	0.90	0.80	0.75
≥ 5	50	0.55	0.45	0.40
	≥ 100	0.75	0.60	0.60

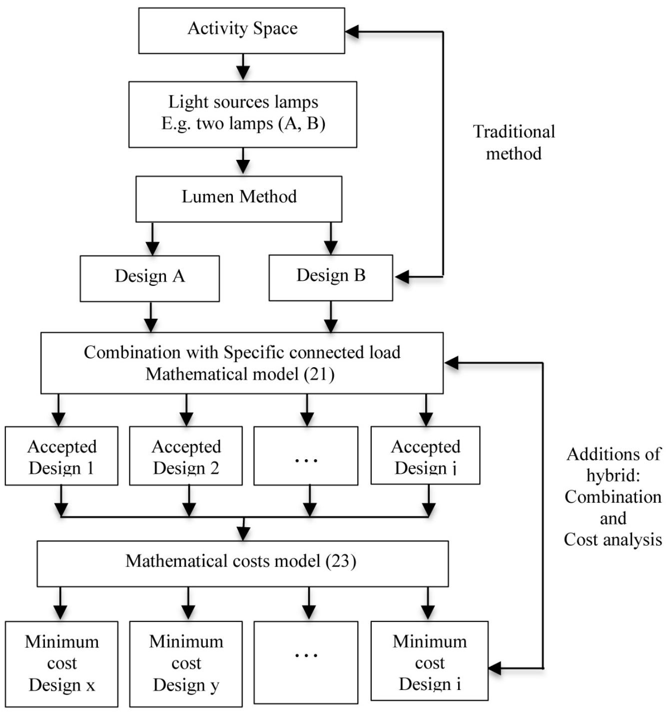

Fig. 1. Structure of proposed hybrid methodology.

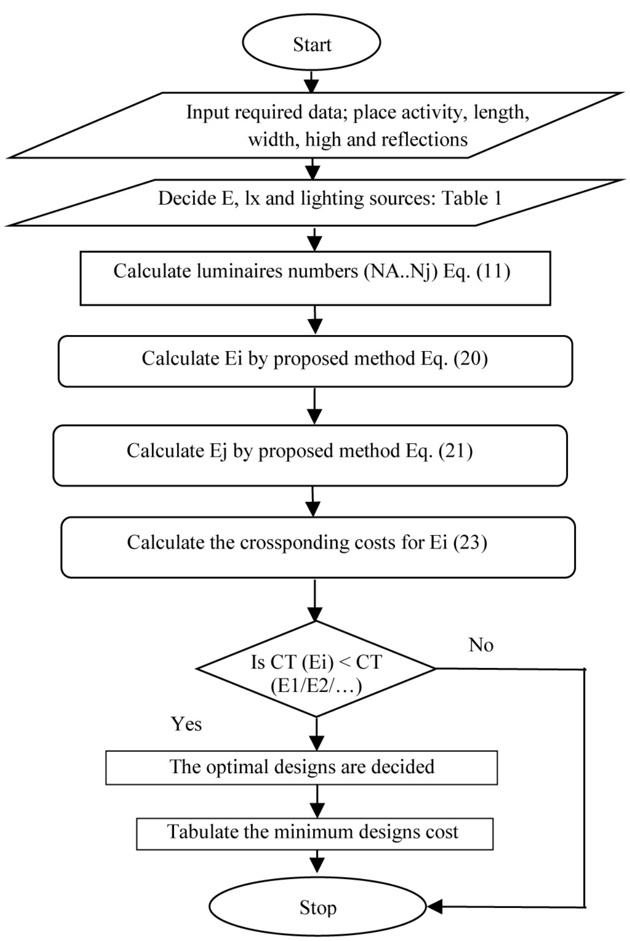

Fig. 2. The Flowchart of the proposed methodology.

luminaire, labour, pipes, wiring, and accessories costs, and the variable "running" costs including operating time costs for energy, material and staff wages carrying out the maintenance and lamp replacement costs.

Therefore, to decide the optimal lighting design, it is important to recognize the following cost equations [47,57]:

$$CT = CF + CR, \$ \tag{8}$$

$$CF = N.C, \$ \tag{9}$$

$$CR = N.t_b.\left(a.P_{lamp} + C1.\left(\frac{1}{t_a} - \frac{1}{t_b}\right) + R\right), \$ \tag{10}$$

2.4.5. Summary

From the above, it can summarize: Each design method is applied individually independent on the others, the applied methods "especially lumen and point by point" depend on the user experience, especially on the programming system, the three methods can be classified as: the first, "Lumen method, common one, gives the average illuminance value and the required luminaire numbers", the second, "Point-by-point method", decides the point to point illuminance, and the third, "Specific connected load method", is rarely used. But, the main disadvantages of these methods are: the blind designs without explanations the main effective factors, i.e., reflection factors, room index, utilance factor, etc., especially the programming methods, e.g., DIALux, Relux, there is no combination between them to enhance the designs efficiency, there is no application for specific connected load method, and there is no design cost analysis model/program to select the optimal designs.

Therefore, the proposed hybrid methodology will overcome these drawbacks.

3. Proposed methodology

This hybrid proposed method will be displayed through the following sections.

3.1. Structure and flowchart

Figures 1 and 2 give the hybrid method full descriptions in the form of the structure and programming and the flowchart, respectively.

According to Figs. 1 and 2; the hybrid proposed method uses the common method "Lumen" for deciding the required numbers of luminaires by the same designer engineering procedures, i.e., similar to other design programs, such as DIALux etc. However, it accomplishes the additional tasks: completing the hybrid methodology by using additional method, combination with specific connected load method, to give the accepted multi-designs, and analysing the accepted designs costs to decide the most savings.

3.2. Proposed methodology mathematical model

The following procedures are accomplished to develop the mathematical model of the proposed methodology.

1. Calculating the appropriate numbers of luminaires according to the space activity "Lumen method":

According to the space activity, the user can decide illuminance "E" and the light source types from Table 1, using Eq. (11) to calculate the required luminaire numbers "N":

$$N = \frac{E.L.W}{\Phi.n.Uf.MF} \quad (11)$$

For example, if the activity space is a meeting room, the used source types "Table 1" may be A, QT or TC. By using Eq. (11), there are three light sources luminaires numbers " N_A, N_{QT} and N_{TC}".

Note that; There are fixed parameters, i.e., ρc, ρw, ρf, MF, L and W, and variables parameters, i.e., Φ, n and Uf, which can be decided according to the light sources "references/manufactures" [54].

2. Deciding the accepted designs by light sources combinations, according to specific connected load method and Eq. (6), the outputs from Eq.(11) " N_A, N_{QT} and N_{TC}"are used and substituted as in (12) "modification of Eq. (6)":

$$E_i = \frac{100.f.P_{LA}}{L.W.P_{CA}}\sum_{i=1}^{NA} Ni + \frac{100.f.P_{LQT}}{L.W.P_{CQT}}\sum_{i=1}^{NQT} Ni + \frac{100.f.P_{Lj}}{L.W.P_{Cj}}\sum_{i=1}^{Nj} Ni, lx \quad (12)$$

where I is the starting and ending numbers according to the light source types "i.e. NA, NQT…Nj", and j; indicates the last light source type number.

For simplification:

$$E_1 = \frac{100.f.P_{LA}}{L.W.P_{CA}}\sum_{i=1}^{NA} Ni \;, E_2 = \frac{100.f.P_{LQT}}{L.W.P_{CQT}}\sum_{i=1}^{NQT} Ni \;, \ldots\ldots E_j = \frac{100.f.P_{Lj}}{L.W.P_{Cj}}\sum_{i=1}^{Nj} Nj \;, \text{lx} \quad (13)$$

$$E_1 = \alpha_A \sum_{i=1}^{NA} Ni \;,\; E_2 = \alpha_{QT} \sum_{i=1}^{NQT} Ni \;, \ldots\ldots E_j = \alpha_j \sum_{i=1}^{Nj} Nj, lx \quad (14)$$

$$\alpha_A = \frac{100.f.P_{LA}}{L.W.P_{CA}} \;, \alpha_{QT} = \frac{100.f.P_{LQT}}{L.W.P_{CQT}}, \ldots\ldots \alpha_j = \frac{100.f.P_{Lj}}{L.W.P_{Cj}} \quad (15)$$

where E_1, E_2 …E_j are the illuminance levels by using light sources A, QT ….. j, respectively.

3. Using the combined matrices

The outputs of the proposed system calculations "two combined methods forN_A and N_{QT}" can give numerous designs:

The combination between the first two types, i.e., N_A and QT, will give a matrix "S1" with (N_A. N_{AQT}) for design cases:

$$A = [1 \quad 2 \quad 3 \ldots\ldots N_A]^T \quad (16)$$

$$QT = [1 \quad 2 \quad 3 \ldots\ldots N_{QT}]^T \quad (17)$$

$$S1 = \begin{bmatrix} \alpha_A + \alpha_{QT} & \cdots & N_A\alpha_A + \alpha_{QT} \\ \vdots & \ddots & \vdots \\ \alpha_A + N_{QT}\alpha_{QT} & \cdots & N_A\alpha_A + N_{QT}\alpha_{QT} \end{bmatrix} \quad (18)$$

Any element of the matrix S1, i.e., accepted Ei, lx, can be estimated from:

$$S_{i,j} = i\alpha_A + j\alpha_{QT}\,,\quad 1 \le i \le N_A, 1 \le j \le N_{QT} \quad (19)$$

By the same manner, the following three matrices are formulated:

$$A = [1 \quad 2 \quad 3 \ldots\ldots N_A]^T \quad (20)$$

$$TC = [1 \quad 2 \quad 3 \ldots\ldots N_{TC}]^T \quad (21)$$

$$S2 = \begin{bmatrix} \alpha_A + \alpha_{TC} & \cdots & N_A\alpha_A + \alpha_{TC} \\ \vdots & \ddots & \vdots \\ \alpha_A + N_{TC}\alpha_{TC} & \cdots & N_A\alpha_A + N_{TC}\alpha_{TC} \end{bmatrix} \quad (22)$$

The accepted Ei is obtained as follows:

$$S_{i,j} = i\alpha_A + j\alpha_{CT}\,,\quad 1 \le i \le N_A, 1 \le j \le N_{TC} \quad (23)$$

$$QT = [1 \quad 2 \quad 3 \ldots\ldots N_{QT}]^T \quad (24)$$

$$TC = [1 \quad 2 \quad 3 \ldots\ldots N_{TC}]^T \quad (25)$$

$$S3 = \begin{bmatrix} \alpha_{QT} + \alpha_{TC} & \cdots & N_{QT}\alpha_A + \alpha_{TC} \\ \vdots & \ddots & \vdots \\ \alpha_{QT} + N_{TC}\alpha_{TC} & \cdots & N_{QT}\alpha_A + N_{TC}\alpha_{TC} \end{bmatrix} \quad (26)$$

The accepted Ei is obtained as follows:

$$S_{i,j} = i\alpha_{QT} + j\alpha_{TC}\,,\quad 1 \le i \le N_{QT}, 1 \le j \le N_{TC} \quad (27)$$

$$A = [1 \quad 2 \quad 3 \ldots\ldots N_A]^T \quad (28)$$

$$QT = [1 \quad 2 \quad 3 \ldots\ldots N_{QT}]^T \quad (29)$$

$$TC = [1 \quad 2 \quad 3 \ldots\ldots N_{TC}]^T \quad (30)$$

$$S4 = \begin{bmatrix} \alpha_A + \alpha_{QT} + \alpha_{TC} & \cdots & N_A\alpha_A + \alpha_{QT} + N_{TC}\alpha_{TC} \\ \vdots & \ddots & \vdots \\ \alpha_A + N_{QT}\alpha_{QT} + N_{TC}\alpha_{TC} & \cdots & N_A\alpha_A + N_{QT}\alpha_{TC} + N_{TC}\alpha_{TC} \end{bmatrix} \quad (31)$$

The accepted Ei:

$$S_{i,j,K} = i\alpha_A + j\alpha_{QT} + k\alpha_{TC}\,,\quad 1 \le i \le N_{QT}, 1 \le j \le N_{QT} \text{ and } 1 \le k \le N_{TC} \quad (32)$$

From the above equations and matrices, the total Ei will be calculated from:

$$E_i = S1 + S2 + S3 + \cdots Si, \text{lx} \quad (33)$$

The accepted Ej will be derived from:

$$E_j = S_{i,j} + \cdots . S_{i,j,K} \ldots ., \text{lx} \quad (34)$$

4. Evaluating the designs costs

The cost calculations and analysis should be accomplished to decide the most economical design:

Using the following modified equations, referred to Eqs. 8-10, for each accepted selected designs, to calculate each accepted design cost:

$$CT(A) = N_A.\left(C(A) + t_b.\left(a.P_{LA} + C1(A).\left(\frac{1}{t_a} - \frac{1}{t_b}\right)\right) + R(A), \$\right. \quad (35)$$

The cost for each accepted designs from Eq.(31) can be calculated by:

$$CT(Si) = N_{Ai}.\left(C(A) + t_b.\left(a.P_{LA} + C1(A).\left(\frac{1}{t_{aA}} - \frac{1}{t_b}\right)\right) + R(A)\right) + N_{QTi}.\left(C(QT) + t_b.\left(a.P_{LQT} + C1(QT).\left(\frac{1}{t_{aQT}} - \frac{1}{t_b}\right)\right) + R(QT)\right) + N_{TCi}.\left(C(TC) + t_b.\left(a.P_{LTC} + C1(TC).\left(\frac{1}{t_{aTC}} - \frac{1}{t_b}\right)\right) + R(TC)\right), \$ \quad (36)$$

Figure 3 displays samples of individual and combined light sources designs.

3.3. Summary

From this section, it can summarize: The proposed methodology will give multi-designs for the same required "E", the numbers of cases "designs" equal the total matrix item outputs from S1+S2+S3+S4 according to Eq. (33), the accepted designs are decided by Eq. (34), the minimum-cost design is decided by Eq. (36), and the calculations are complex and need longer times.

4. Case studies

This section highlights the case studies with: conventional lamps and tubes "case study 1" and LED lamps "case study 2". These

Fig. 3. Samples of individual and combined designs of light sources (**a**) design of light source 1, (**b**) design of light source 2, and (**c**) combination of two light sources "1 and 2".

Table 5. Data of case study 1 "supposed and derived".

Given data "Supposed"									Derived dada							
Activity place	L, m	W, m	Ht, m	Hs, m	Working level, m	*ρc*	*ρw*	*ρf*	E, lx "Table 1"	Light source types, "Table 1and [54]"	MF, very clean "Table 2"	Kr, "Eq. (4) and (5) "	Uf, T26-18 W [62]	Uf, TC-9 W [63]	Lifetimes/ lm "T26-18 W" [54]	Lifetimes/lm "TC-9 W" [54]
Laboratory	5	6	3.5	0	0.8	0.7	0.5	0.2	500	T26-18 W and TC-9 W"	0.85	1.01	0.51	0.45	7000 h /1350 lm	8000 h/ 600lm

cases will be implemented in Egypt according to price lists of local products companies. The calculations will be performed by manual calculations, where the user can recognize in detail how to use this proposed hybrid methodology, and by fast and simple verification of MATLAB® program.

4.1. Case study 1

4.1.1. The hybrid method manual calculations

These manual calculations comprise the basic designs using Lumen method with preferable light sources according to activity space [54], combination with specific connected loads method and generating the most economic multi-design cases.

4.1.1.1. Basic designs

Suppose the activity place has the following data described in Table 5:

Table 5 data analysis: Light lamp "TC-9 W" is similar in its features and curves to lamp type "Eco Home LED Bulb 10W E27 6500KHV 1CT/48AR, Philips-leaflet [63]", which gives Uf = 0.41-0.45, in the individual lighting design; the used luminaire numbers should be integer "not fraction", therefore the required luminaires for N (T26) = 13/14 (each luminaire has 2 lamps), and the required for N (TC) = 66 lamps, the decided numbers should verify the required illumination level "E = 495-505 lx ", for individual design, the required numbers of luminaires must be even not odd "N (T26) = 14", and these calculations can be applied by dividing the activity space into multi sections with different illuminance "E" values according to the advisements of [48,49].

However, the main aim in this study is to display how to use this proposed hybrid methodology in a general form "the methodology can be applied for different E values in the same activity space to give the same savings".

By using Eq. (11), the required luminaires numbers for two light sources are:

$$N(T26) = \frac{500.5.6}{1350.2.0.51.0.85} = 12.8155 \quad (37)$$

$$N(TC) = \frac{500.5.6}{600.0.45.0.85} = 65.359 \quad (38)$$

4.1.1.2. Specific connected loads application

According to Table 4 with area = 30 m^2 "6. 5, 20< 30 <50", H =3.5 m "3< Ht <5" and the reflection factors from Table 5; the correction factor "f" is the average of two values "the value between 0.55 and 0.75 in Table 4" = (0.55+ 0.75)/2 = 0.65,

The specific connected load "P_c" can be taken from Table 3 or by the direct calculations by using Eq. (6) where N(T26)=12.8155, the value of P_C for light source T26 is:

$$P_C(T26) = \frac{36.100.12.8155.0.65}{500.5.6} = 1.9992, (W/m^2.100lx) \quad (39)$$

N (TC) = 65.359, the value of P_C for light source TC is:

$$P_C(TC) = \frac{9.100.65.359.0.65}{500.5.6} = 2.549, (W/m^2.100lx) \quad (40)$$

Explanations: The numbers of luminaires are taking directly from the basic design calculations "N(T26)=12.8155 and N(TC)=65.359", and the required values of "P_c" don't need to reach the nearest integer unlike in the design case.

4.1.1.3. Design costs

Table 6 gives the full data about the fixed and running costs "E£" according to the two decided light sources, i.e., T26-18 W and TC-9 W, the referenced Egyptian products company [68], experiences in this field and average Egyptian tariff [69].

Table 6 data analysis: Lifetime "tb" that is suggested to be 20000 h referes to the lifetime of the light source fixture and electrical installations "not lamps". For example, if the duty operation of a lamp is 12 h/day, then the operation times through one year = 4380 h. The fixture lifetime, by using 20000 h, is now corresponding to 4.566 years, which is very low lifetime for any light source fixture, the prices in Table 6 are the commercial prices in the Egyptian market corresponding to the given light sources features, e.g., the price of TC-9 W produced by Toshiba Egypt [68] is 37.5 E£, which has 25000 h lifetimes and 900 lumens. The used lamp in this study operates 8000 h with 600 lumens [54], which leads to reducing the lamp price, the commercial price = 10 E£, the rate of maintenance, i.e., cost/year R, E£ or $, is taken as the minimum rate of maintenance that takes into account the number of lamps /light source, e.g., for T26 there are two lamps with R = 1 E£. On the other hand for TC-9 W, there is one lamp with R = 0.5 E£. These values are set based on the experience in the practical field, according to [70], the yearly person consumed energy (2017-2018) is 2016 kWh which means that in case of family constituting of 4 persons as an average number, the yearly energy is 8064 kWh and the monthly consumed energy is 672 kWh and the Egyptian tariff of a =0.75 E£/kWh is assumed as an average value [69] "this assumption is based on the consumed energy, i.e., 672 kWh/M, where the tariff is in the range between 0.70 - 0.9 E£".

Table 6. Light sources data and costs [68, 69].

Factors	Light sources types	
	T26	Tc-9 w
Lamp price, E£	8	10
No. lamps	2	1
Total lamps costs, E£	16	10
Luminaire/Lamp base price, E£	20	5
Chock coil and accessories price, E£	20	--
Supply point price, E£	5	3
Total fixed costs, E£	61	18
ta, h from [54]	7000	8000
tb, h "suggested", hours	20000	20000
R, E£ "suggested"	1	0.5
a, E£: tariff/kWh[69]	0.75	0.75

Note that; the dollar exchange rate is 16 E£.

By substuiting from Table 6 data into Eq. (35):

The cost of light source "T26", E£:

$$CT(T26) = 14\left(61 + 20000\left(\frac{0.75.36}{1000} + 16\left(\frac{1}{7000} - \frac{1}{20000}\right)\right) + 1\right) = 8843.99\, E£ = 552.749\, \$ \quad (41)$$

The cost of light source "TC", E£:

$$CT(TC) = 66\left(18 + 20000\left(\frac{0.75.9}{1000} + 10\left(\frac{1}{8000} - \frac{1}{20000}\right)\right) + 0.5\right) = 11121\, E£ = 695.06\, \$ \quad (42)$$

4.1.1.4. The hybrid method optimal desgins

4.1.1.4.1. Application with fixed lifetime value

By using Eqs. (12-14), (18), (33-36), the calculated values of illuminances for two light sources "variation with luminaire numbers" are as follows:

$$Ei = \frac{36.100.Ni.065}{1.9992.5.6} = 39.01Ni, lx \quad (43)$$

$$Ej = \frac{9.100.Ni.065}{2.549.5.6} = 7.65Nj, lx \quad (44)$$

Note that; Illuminances calculations "Ei" for light source "T26, i :1 to 14", give 14 different values of E1, illuminances calculations "Ej" for light source "TC, j :1 to 66", give 66 different values of E2, the combination of these values "Ei and Ei", generates 924 different values as in Table 7, and the accepted values decide by Ei+ Ej = 500±1%=495-505 lx from the 924 values.

Table 7 shows combination accepted values "cases" i.e. 495≤Ei+ Ej≤ 505 lx, (e.g. E (T26) = 468.12 lx at N (T26) = 12, E (TC) = 30.6 lx at N (TC) = 4 "same row". The combination of these values is 498 lx "accepted", this can be applied for the same table rows.

Note that; The costs of these accepted values are decided and compared with the cost of basic individual designs to decide the optimal minimum designs.

From the general cost form given by Eq. (35):

The cost for each number of light source "T26", E£:

$$CT(T26) = Ni\left(61 + 20000\left(\frac{0.75.36}{1000} + 16\left(\frac{1}{7000} - \frac{1}{20000}\right)\right) + 1\right) = 631.714\, Ni, E£ \quad (45)$$

The cost for each number of light source "Tc", E£:

Table 7. The various accepted and unaccepted values of E (T26) and E (TC).

Accepted cases						**Un-accepted cases**			
Case No.	N T26	E1, lx	N TC	E2, lx	Ei, lx (=E1+E2)	N(T26)	E1, lx	N(TC)	E2, lx
1	1	39.01	60	459	498.01	13	507.13	1	7.65
2	2	78.02	55	420.75	498.77	14	546.14	2	15.3
3	3	117.03	50	382.5	499.53			3	22.95
4	4	156.04	45	344.25	500.29			5	38.25
5	5	195.05	40	306	501.05			6	45.9
6	6	234.06	35	267.75	501.81			7	53.55
7	7	273.07	30	221.85	502.57			8	61.2
8	8	312.08	24	183.6	495.68			10	76.5
9	8	312.08	25	191.25	503.33			11	84.15
10	9	351.09	19	145.35	496.44			12	91.8
11	9	351.09	20	153	504.09			13	99.45
12	10	390.1	14	107.1	497.2			16	122.4
13	10	390.1	15	114.75	504.85			17	130.05
14	11	429.11	9	68.85	497.96			:	:
15	12	468.12	4	30.6	498.72			66	504.9

Table 8. The accepted values of E1 and E2 with their accompanied numbers of luminaires/lamps and costs "E£".

Case No.	**N T26**	**E1, lx**	**N TC**	**E2, lx**	**Ei, lx (=E1+E2)**	**CT(E1+E2) E£**	**CT(E2) E£**	**CT(E1) E£**
1	1	39.01	60	459	498.01	10741.714	10110	631.714
2	2	78.02	55	420.75	498.77	10530.928	9267.5	1263.428
3	3	117.03	50	382.5	499.53	10320.142	8425	1895.142
4	4	156.04	45	344.25	500.29	10109.356	7582.5	2526.856
5	5	195.05	40	306	501.05	9898.57	6740	3158.57
6	6	234.06	35	267.75	501.81	9687.784	5897.5	3790.284
7	7	273.07	30	221.85	502.57	9476.988	5055	4421.998
8	8	312.08	24	183.6	495.68	9097.712	4044	5053.712
9	8	312.08	25	191.25	503.33	9266.212	4212.5	5053.712
10	9	351.09	19	145.35	496.44	8886.926	3201.5	5685.426
11	9	351.09	20	153	504.09	9055.426	3370	5685.426
12	10	390.1	14	107.1	497.2	8676.14	2359	6317.14
13	10	390.1	15	114.75	504.85	8844.64	2527.5	6317.14
14	11	429.11	9	68.85	497.96	8465.354	1516.5	6948.854
15	12	468.12	4	30.6	498.72	8254.568	674	7580.568

$$CT(TC) = Ni\left(18 + 20000\left(\frac{0.75.9}{1000} + 10\left(\frac{1}{8000} - \frac{1}{20000}\right)\right) + 0.5\right) = 168.5\ Ni, E£ \quad (46)$$

Table 8 data analysis: The column number six gives the accepted E values, e.g., 312.08+183.6 = 495.68 lx, the numbers in column number seven "CT", give all cases with costs lower than the costs of "TC–9 W" and "T26-18 W" light sources design "related their costs".

Table 9 analysis the cost savings "E£" by the proposed hybrid method instead of two individual designs of light sources, which uses lumen method only".

4.1.1.4.2. Application with variable lifetime values

- The costs of the two light sources that vary with N and tb are given as follows:

$$CT(T26) = N_i\left(61 + tb\left(\frac{0.75.36}{1000} + 16\left(\frac{1}{7000} - \frac{1}{tb}\right)\right) + 1\right), E£ \quad (47)$$

$$CT(TC) = N_i\left(18 + \text{tb}\left(\frac{0.75.9}{1000} + 10\left(\frac{1}{8000} - \frac{1}{\text{tb}}\right)\right) + 0.5\right), \text{E£} \quad (48)$$

- Substituting in the individual designs with N(T26) = 14, N(TC) = 66 and tb =4380 h, the costs can be calculated for CT (T26) and CT (TC), where CT (T26) = 2439.8 E£ and CT (TC) = 2873.64 E£,
- The operation lifetime values "tb" affects the percentages of hybrid method saving. "TC-9 W" is taken as a base case for comparisons as displayed in Table 10. The lifetime values rang from tb = 4380 h up to tb = 50000 h,
- The data for the proposed method are taken according to the "accepted cases, from Table 8" for the 15 cases regarding the values of (T26) and N (TC) in column 2 and 4 in Table 8.

Table 9. Savings with the proposed method instead of two individual light sources designs (derived from Table 8).

Case No.	Proposed method related to lumen method of T26 (8843.99 E£)		Proposed method related to lumen method of TC (11121 E£)	
	Saving money, E£	**%Saving instead of lumen method of T26**	**Saving money, E£**	**%Saving instead of lumen method of TC**
1	-	-	379.286	3.41
2	-	-	590.072	5.30
3	-	-	800.858	7.20
4	-	-	1011.644	9.09
5	-	-	1222.43	10.99
6	-	-	1433.216	12.88
7	-	-	1644.012	14.78
8	-	-	2023.286	18.19
9	-	-	1854.788	16.67
10	-	-	2234.074	20.08
11	-	-	2065.576	18.573
12	167.85	1.898	2444.86	21.98
13	-	-	2276.36	20.46
14	378.636	4.2812	2655.646	23.879
15	589.422	6.664	2866.432	25.774

Table 10. Effectiveness of light sources lifetime values "tb" on the percentages saving.

Item	Costs and savings "tb = 4380 h", E£			Costs and savings "tb = 7000 h", E£			Costs and savings "tb = 20000 h", E£			Costs and savings "tb = 30000 h", E£			Costs and savings "tb = 50000 h", E£		
Types	Traditional: TC, L£,	Proposed: T26+ TC, E£	% Savings	Traditional: TC, L£,	Proposed: T26+ TC, E£	% Savings	Traditional: TC, L£,	Proposed: T26+ TC, E£	% Savings	Traditional: TC, L£,	Proposed: T26+ TC, E£	% Savings	Traditional: TC, L£,	Proposed: T26+ TC, E£	% Savings
Case 1	2873.64	2786.7	3.0364	4257	4121	3.194	11121	10741.714	3.41	16401	15834.571	3.453	26961	26020.28	3.48
. . . Case 2	2873.64	2743.2	4.5377	4257	4049.5	4.873	11121	10530.928	5.30	16401	15516.642	5.392	26961	25488.07	5.46
Case 8	2873.64	2439.1	15.1206	4257	3556	16.466	11121	9097.712	18.19	16401	13360.568	18.538	26961	21886.24	18.822
. . . Case 10	2873.64	2395.7	16.6319	4257	3484.5	18.1466	11121	8886.926	20.08	16401	13042.63	20.47	26961	2154.065	20.796
Case 15	2873.64	2265.4	21.1658	4257	3270	23.1853	11121	8254.568	25.774	16401	12088.852	26.29	26961	19757.42	26.71

- Figure 4 illustrates the variation of percentage savings for the 15 cases "percentages saving" depending on lifetime's values for tb from 4380 to 50000 h.

Table 10 and Fig. 4 data analysis: The lifetime increase causes corresponding increase in the percentages saving, the minimum lifetime value "tb =4380 h" that is very low, gives percentage savings from 3.03% to 21.163% related to the traditional design, by using T26 light source lifetime "tb = 7000 h", percentage savings will range from 3.194% up to 23.1853% related to the traditional design and generally, there are considerable percentage savings for any supposed lifetime values.

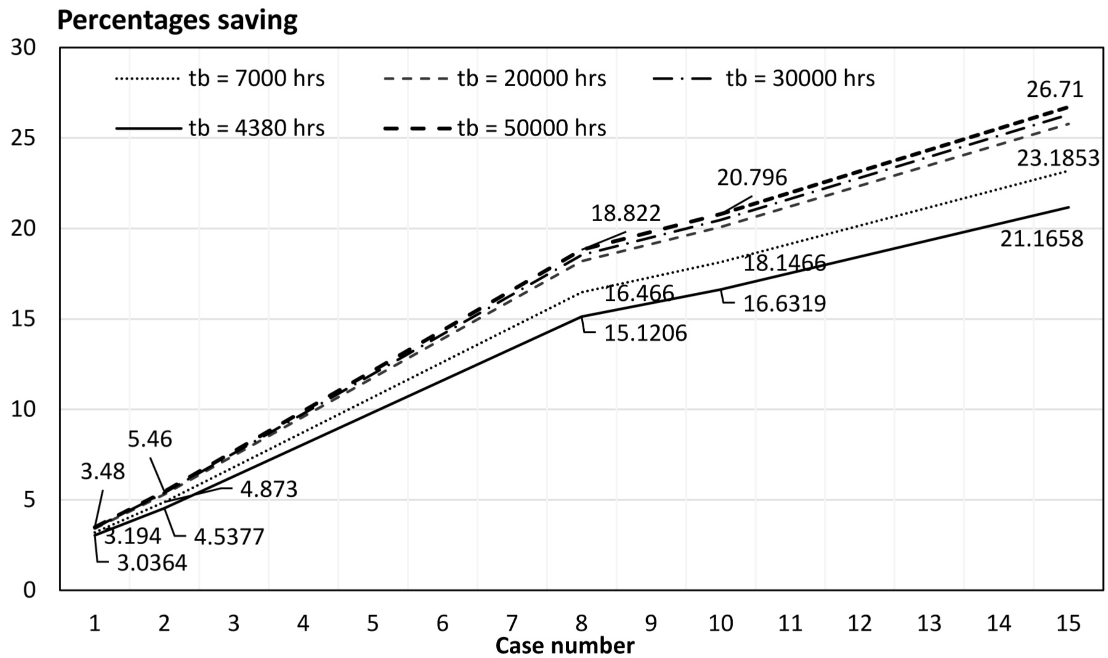

Fig. 4. Variation of percentage savings depending on lifetime values.

Table 11. The accepted E and the accompanied numbers.

Case no.	E, Lx	N(TC)	N(T26)
1	498.010	60	1
2	498.77	55	2
3	499.53	50	3
4	500.29	45	4
5	501.05	40	5
6	501.81	35	6
7	502.57	30	7
8	495.68	24	8
9	503.33	25	8
10	496.44	19	9
11	504.09	20	9
12	497.20	14	10
13	504.85	15	10
14	497.96	9	11
15	498.72	4	12

Table 12. The accepted E with costs "lower than TC cost", E£.

Case no.	Costs, E£	N(TC)	N(T26)
1	10741.71	60	1
2	10530.9280	55	2
3	10320.1420	50	3
4	10109.3560	45	4
5	9898.570	40	5
6	9687.7840	35	6
7	9476.9980	30	7
8	9097.7120	24	8
9	9266.212	25	8
10	8886.9260	19	9
11	9055.4260	20	9
12	8676.140	14	10
13	8844.640	15	10
14	8465.3540	9	11
15	8254.5680	4	12

4.1.2. Developed MATLAB® program

All the previous equations, calculations, data, parameters and mathematical model applications can be performed by developing a program tool on MATLAB® package [71]. This program can give the multi-designs with any numbers of light sources by fast and accurate manner. For example, the following tables give the same previously discussed designs for the two light sources "T26 and TC" by the MATLAB® proposed program instead of manual calculations.

Table 11 gives the accepted design cases "495≤E≤505, lx, similar to Table 7", while Table 12 displays the accepted values of Ei, which satisfy since the costs of these accepted values "E1+E2" are lower than the cost of TC light source "11121 E£", which is similar to values in Table 8.

By using hybrid MATLAB® program, the percentage savings with respect to T26 and TC are shown in Tables 13 and 14, respectively, where the results are similar to the manual calculations in Table 9.

The maximum lifetime of fixture tb in Tables 13 and 14 is 20000 h "low lifetime value", which increases the percentages saving from 1.898% to 25.774%.

4.2. Case study 2

By the same manner and procedures, case study "2" can be implemented, by hybrid methodology, using LED lamps to verify that hybrid system can be applied for any lamp type with considerable percentage savings. This case study uses the same data in the previous case "case study 1" with some modifications as in Table 15.

Table 15 data analysis: Light lamp types "9W-60 cm TM-D10H" and "9 W -White Light BM-D09H" are from Egypt Toshiba Elaraby Company [68], the values of Uf for these lamps are not found in the datasheets of Elaraby Company. Therefore, reference [68] is used to obtain the values of Uf: Light lamp "9W-60 cm TM-D10H, Toshiba [68]" is similar in its features and curve to lamp type "Ecofit LED tube HO 600mm 10W 765 T8 RCA, Philips-leaflet [63]", which gives Uf = 0.53, and light lamp "9 W -White Light BM-D09H, Toshiba [68]" is similar in its features and curve to lamp type "Eco Home LED Bulb 10W E27 6500KHV 1CT/48AR, Philips-leaflet [63]", which gives Uf = 0.41.

By using Eq. (11), the required fixtures "luminaires" numbers for the two light sources are:

$$N(TM-D10H) = \frac{500.5.6}{1000.2.0.53.0.85} = 16.6480 \quad (49)$$

Table 13. The percentages saving of hybrid system compared to T26.

Case no.	Costs, E£	Savings, E£	Percentages saving, %
1	8676.140	167.80	1.898
2	8465.354	378.636	4.281
3	8254.568	589.421	6.665

Table 14. The percentages saving of hybrid system compared to TC.

Case no.	Costs, E£	Savings, E£	Percentages saving, %
1	10741.71	379.286	3.41
2	10530.9280	590.072	5.305
3	10320.1420	800.858	7.2013
4	10109.3560	1011.644	9.0966
5	9898.570	1222.430	10.992
6	9687.7840	1433.216	12.887
7	9476.9980	1644.002	14.782
8	9097.7120	2023.288	18.193
9	9266.212	1854.788	16.678
10	8886.9260	2234.074	20.088
11	9055.4260	2065.574	18.573
12	8676.140	2444.860	21.984
13	8844.640	2276.360	20.4690
14	8465.3540	2655.646	23.8795
15	8254.5680	2866.432	25.774

$$N(BM-D09H) = \frac{500.5.6}{800.0.41.0.85} = 53.802 \quad (50)$$

Note that: N (TM-D10H) = 18 (each luminaire has 2 lamps), and the required for N (BM-D09H) = 54 lamps.

The specific connected loads, using the same parameters in case 1, can be calculated by Table 3 or by the direct calculations using Eq. (6) where:

N(TM-D10H) =16.6480, the value of P_C for light source (TM-D10H):

$$P_C(TM-D10H) = \frac{18.100.16.6480.0.65}{500.5.6} = 1.2985, (\frac{W}{m^2}.100\ lx) \quad (51)$$

N(BM-D09H) = 53.802, the value of P_C for light source (BM-D09H):

$$P_C(BM-D09H) = \frac{9.100.53.802.0.65}{500.5.6} = 2.0982, (\frac{W}{m^2}.lx) \quad (52)$$

The light source costs are shown in Table 16 "taken the tariff = 0.70 E£/kWh".

Eq. (35) can use the data in Table 16 to calculate the two light sources costs:

The cost of light source "TM-D10H", E£:

$$CT(TM-D10H) = 18\left(161 + 20000\left(\frac{0.70.18}{1000} + 73\left(\frac{1}{25000} - \frac{1}{20000}\right)\right) + 1\right) = 7189.2\ E£ = 449.325\ \$ \quad (53)$$

The cost of light source "BM-D09H", E£:

$$CT(BM-D09H) = 54\left(45.5 + 20000\left(\frac{0.70.9}{1000} + 37.5\left(\frac{1}{25000} - \frac{1}{20000}\right)\right) + 0.5\right) = 8883\ E£ = 555.1875\ \$ \quad (54)$$

$$Ei = \frac{18.100.Ni.065}{1.9285.5.6} = 30.0346Ni, lx \quad (55)$$

By using Eq. (6), the values of two light sources illuminance are:

$$Ej = \frac{9.100.Ni.065}{2.0982.5.6} = 9.293Ni, lx \quad (56)$$

Note that; Illuminances calculations "Ei" for light source "M-D10H, i: 1 to 18", give 18 different values of E1, and illuminances calculations "Ej" for light source "BM-D09H, j: 1 to 54", give 54 different values of E2.

The two light sources costs with variation of luminaires numbers:

$$CT(TM-D10H) = 399.4\ Ni, E£ \quad (57)$$

$$CT(BM-D09H) = 164.5Nj, E£ \quad (58)$$

According to given data, equations and by application of hybrid method on MATLAB® package, the final cost and percentages savings can be shown in Tables 17 and 18.

Tables 17 and 18 data analysis: This hybrid system is effective in saving money with any light source type and the percentages

Table 15. Case study 2 data "supposed and derived".

Given data "Supposed"									Derived dada							
Activity place	L, m	W, m	Ht, m	Hs, m	Working level, m	ρc	ρw	ρf	E, lx "Table 1"	Light sources types, LED " [68]"	MF, very clean "Table 2"	Kr, "Eq. (4) and (5) "	Uf, 9W-60 cm TM-D10H [63]	Uf, 9 W -White Ligh BM-D09H [63	Lifetimes/ lm "9W-60 cm TM-D10H" [68]	Lifetimes/lm "9 W -White Light BM D09H" [68
Laboratory	5	6	3.5	0	0.8	0.7	0.5	0.2	500	"9W-60 cm TM-D10H" and "9 W -White Light BM-D09H"	0.85	1.01	0.54	0.45	25000 h /1000 lm	25000 h/ 800lm

Table 16. Light sources data and costs [68,69].

Factors	Light sources types	
	TM-D10H	BM-D09H
Lamp price, E£	73	37.5
No. lamps	2	1
Total lamps costs, E£	146	37.5
Luminaire/Lamp base price, E£	10	5
Supply point price, E£	5	3
Total fixed costs, E£	161	45.5
ta, h from Figure 1	25000	25000
tb, h "suggested", hours	25000	25000
R, E£ "suggested"	1	0.5
a, E£: tariff/kWh[61]	0.70	0.70

saving range from 0.3199% up to 24.3566% "tb from 20000 h up to 500000 h".

4.3. Verification of the proposed hybrid method

According to the previous sections, the proposed hybrid method succeeded to introduce high efficient methodology to overcome the most drawbacks of traditional methods, since it generates multi-accepted and most economical designs from two individual designs. This hybrid method success to give multi accepted and minimum lighting design calculations, the remained final step in lighting design is deciding the numbers of luminaires in the activity space length and width. The distribution of luminaires through activity space can calculated by [54-56]:

$$N_L = \sqrt{\frac{N \times L}{W}} \quad (59)$$

$$N_W = \sqrt{\frac{N \times W}{L}} \quad (60)$$

where N_L is the distributed luminaire numbers of the space length and N_W is the distributed luminaire numbers of the space width. To verify the accuracy of results obtained by the proposed hybrid method, the results of "case study 2" are compared with that obtained by a standard program, i.e., DIALux program (4.12.1) and according to [48,49] by using two designs: individual design of light lamp "9W-60 cm TM-D10H/Ecofit LED tube HO 600mm 10W 765 T8 RCA" and proposed hybrid method with case 17 in Table 18 "case 4 in Table 17".

4.4. Application of the proposed methodology in Egypt

According to reports through 2014-2018 [69], the residential and commercial sectors consume more than 56% of the total electricity consumption in Egypt "2017-2018". The household electricity consumption of lighting is estimated to be 30%, while consumption of entertainment devices is 15% and that of fridges is 13% representing the largest parts of residential electricity consumption. The total annual Egyptian energy consumed through 2017-2018 in commercial and residential sectors are 75181 MWh. The lighting systems consumed about 30% of the total

Table 17. The percentages saving of hybrid system compared to M-D10H, 7513.2 E£.

Case No.	N (M-D10H)	N (BM-D09H)	Proposed Costs, E£	Savings, E£	Percentages saving, %
1	13	12	7166.2	23	0.3199
2	14	9	7072.1	117.10	1.6288
3	15	5	6813.5	375.70	5.2259
4	16	2	6719.4	469.80	6.5348

Table 18. The percentage savings of hybrid system compared to BM-D09H, 9369 E£.

Case No.	N (M-D10H)	N (BM-D09H)	Proposed Costs, E£	Savings, E£	Percentages saving, %
1	1	51	8788.90	94.10	1.0593
2	2	47	8530.30	352.70	3.9705
3	3	44	8436.20	446.80	5.0298
4	4	41	8342.10	540.90	6.0892
5	5	38	8248	635	7.1485
6	6	34	7989.40	893.60	10.0597
7	7	31	7895.30	987.70	11.1190
8	8	28	7801.20	1081.80	12.1783
9	9	25	7707.10	1175.9	13.2376
10	10	21	7448.50	1434.5	16.1488
11	10	22	7613	1270	14.2970
12	11	18	7354.40	1528.6	17.2082
13	12	15	7260.30	1622.7	18.2675
14	13	12	7166.20	1716.8	19.3268
15	14	9	7072.10	1810.9	20.3861
16	15	5	6813.50	2069.5	23.2973
17	16	2	6719.40	2163.6	24.3566

Table 19. The percentage savings of hybrid system compared to T26.

Case No.	Costs (T26), E£	Savings, E£	Percentages saving, %
1	2439.1	0.6720	0.0275
2	2395.7	44.1010	1.8076
3	2439.2	0.5610	0.0230
4	2352.3	87.530	3.5876
5	2395.8	43.990	1.8030
6	2308.8	130.959	5.3676
7	2265.4	174.388	7.1476

Table 20. The percentage savings of hybrid system compared to TC.

Case No.	Costs (TC), E£	Savings, E£	Percentages saving, %
1	2786.7	86.969	3.0264
2	2743.2	130.398	4.5377
3	2699.8	173.827	6.049
4	2656.4	217.256	7.5603
5	2613.0	260.685	9.0716
6	2569.5	304.114	10.5829
7	2526.1	347.543	12.0942
8	2439.1	434.512	15.1206
9	2482.7	390.972	13.6055
10	2395.7	477.941	16.6319
11	2439.2	434.410	15.1168
12	2352.3	521.370	18.1432
13	2395.8	477.830	16.6280
14	2308.8	564.799	19.6545
15	2265.4	608.228	21.1658

Table 21. Energy and money savings with the proposed methodology "Egypt application".

% Saving	% Savings in consumed lighting energy in residential and commercial sectors, GWh (22554.3)	% Savings in Money, millions E£ "a = 0.75"
0.0230	5.1874	3.890
0.0275	6.202	4.6515
1.8030	406.654	304.9905
1.8076	407.691	305.76825
3.0264	682.5833	511.9374
3.5876	809.158	606.8685
:	:	:
21.1658	4773.7980	3580.348522

consumption, i.e., 30% of 75181 = 22554.3, which is a very high consumption.

The following points should be noticed:

- The average lighting system operations through four seasons in Egypt is 12 h/day [69,70]. This means that, the yearly light operation time is 365×12 = 4380 h. This value will be used instead of 20000 h in calculations to verify the savings will be executed for very low lifetime value.
- The result values by application of Eqs. (35) and (36) with tb = 4380 h, CT (T26) = 2439.8 E£, and CT (TC) = 2873.64 E£, are shown in Tables 19 and 20 as obtained from the MATLAB® program.

If the proposed methodology is applied for the Egyptian lighting system, commercial and residential sectors, considerable savings in energy and money will be achieved as shown in Table 21 assuming the average tariff = 0.75 E£/kWh [69,70]. Table 21 describes the growth in energy and money savings with this effective hybrid method. The savings in energies vary from 5.1874 to 4773.7980 GWh/y and the savings in money start from 3.890 up to 3580.348522 million E£, ≈ 223.7717 million $, for only one year.

From the above, it can summarize: Practically, the light source fixture lifetime value not less than 10 years, which means that the operating times are 43800 h, by applying tb = 43800 in hybrid methodology using MATLAB® program, the percentage saving reaches to 26.54% related to TC-9 W light source as shown in Fig. 5, which displays the various percentage savings for each case of the 15 accepted cases in Table 11 with variation of lifetime values "tb" from 4380 up to 43800 h, by using the highest percentage saving, i.e., 26.54%, the saving in energy is 5985.911GWh/Y and the corresponding money saving is 4489.433415 million E£, or 280.5895 million $, each year.

The user of the program can select any range of lifetime values to display the various percentage savings by the MATLAB® program.

5. Discussion

The lighting design systems, either calculations or programming, depend on single design method, almost Lumen, which gives individual design for each light source. These conventional methods are limited systems to get multi-designs probability and the decided designs do not provide cost analysis report. The hybrid proposed system in this study can overcome these lighting systems drawbacks, with clear methodology and mathematical applicable model. Through case studies and their obtained results, this hybrid system ensured its ease to be applicable for any activity spaces with multi-divisions through a simple MATLAB® program. The methodology is effective in achieving a considerable percentages saving for any light source type and their percentages saving increase by increasing the lifetime values as shown in Fig. 5. By application of this system in Egypt case, the results of percentages saving for energy and money are very satisfying. This hybrid system is compared by the standard program "DIALux" to verify its accuracy and effectiveness in energy and money savings. This hybrid MATLAB® program needs to direct link with any of drawing lighting design programs "e.g. DIALux" to supply its designs data automatically without manual user inputs "Future work".

6. Conclusions

A proposed method that merges the common design calculation method "Lumen" with combined method "specific connected loads" and applies cost analysis by mathematical model is introduced to give new trend in lighting designs. This technique can overcome the drawbacks of the traditionally used methods. The conclusions behind the benefits of this hybrid method can be summarized as: It focuses on the explanation of this new hybrid methodology to the user, it has a new mathematical model, this methodology has multi calculations and procedures to give

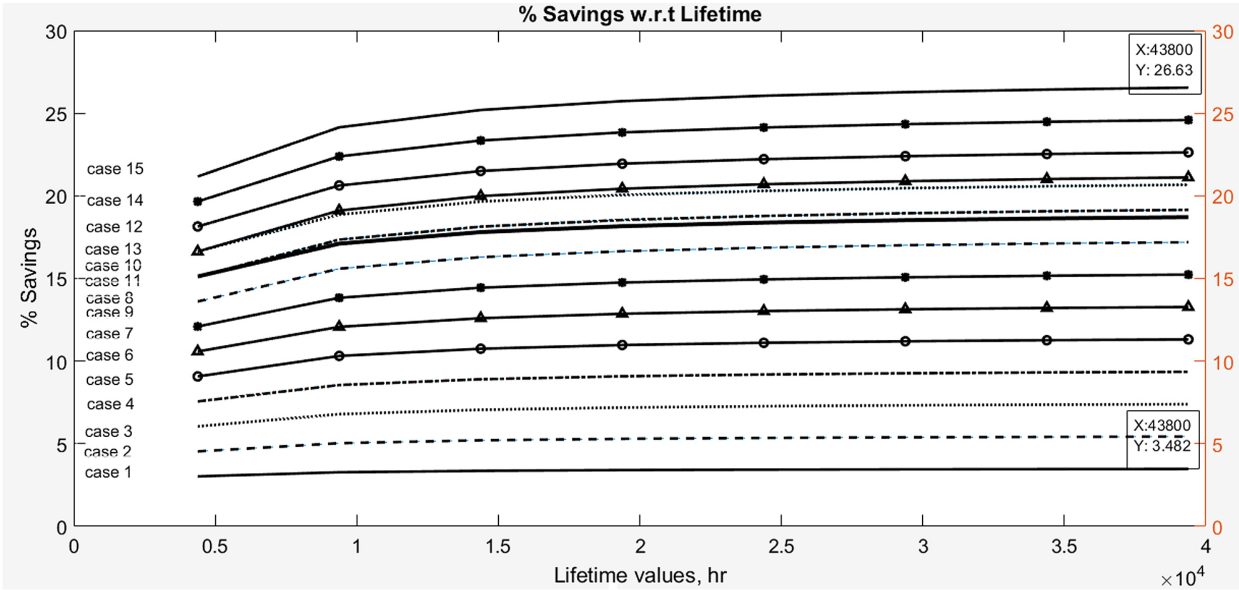

Fig. 5. The percentages saving increased by the extending light source lifetimes (from 4380 up to 43800 h for TC light sources).

accurate results, it can deal with any numbers of light sources and activity spaces at the same times, gives the largest numbers of accepted multi-designs according to standards and given conditions from individual design, these multi-choices lighting designs will give the design engineer the facilities to give the most effective and aesthetic design of the light sources for the given activity, e.g., reception, office room, etc., it analyses the costs of accepted designs to reach the most economic multi-designs, it helps to get the highest percentages saving as explained in Tables 13 and 14, which varies from 1.89% up to 25.7749% of the traditional designs costs, the percentages saving increases by the increase of fixture lifetime, which can reach to 26.63% by a lifetime value of tb = 43800 h as shown in Fig. 5, by practical application of this hybrid method in Egypt, the system achieves considerable savings in consumed lighting energy and money "which ranges from 3.890 to 4489.433415 million E£, i.e., 280.5895 million $", the effectiveness of the methodology is verified regarding the energy and money savings by comparing a case study "2" with DIALux program, and the algorithm can be easily executed by developing a MATLAB® program to solve the problems of the longer procedures and the complexity of the multi-calculations. This open code program can perform all calculations and give the results within 20-30 s, instead of many hours using manual calculations.

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Contributions

Dr. F. Selim: He is the main author of the research with contributions including idea and methodology of the entire research, except for a special part in parts of programming equations. Helping was done through Dr. S. M. Elkholy. She made a combination of the two traditional methods to give the proposed method, Dr. S. M. Elkholy helped in equations and the program. Dr. Ahmed F. Bendary performed a complete review of the research, corrected engineering and linguistic errors, and helped in deleting some unhelpful paragraphs. He reviewed the important paragraphs: abstract, proposed methodology steps, conclusions.

Declaration of competing interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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