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Article

Accurate Sustainable Indoor-Lighting Design Using Simultaneous Dual Control to Adjust LEDs Lighting and Roller Blinds' Opening to Control the Daylight for Economic Power Consumption

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Abstract: Global temperature rise due to hydrocarbon gases emission that are produced by generating the electrical power has a great attention by the researchers to reduce it till zero emission is successfully achieved. Sustainable energy source such as solar energy, wind, hydro-energy and sea wave energy are focal areas to replace the fossil fuel by clean energy. In this article, daylight is used to minimize the power consumption that required for indoor lighting using electric roller blind. Smart controller is designed to adjust the position of the roller blind stepper motor, and hence, adjust the roller blind opening, based on the preset light intensity, to achieve precise utilization of daylight inside the room. If the desired Lux is not achieved for any reason, the smart controller adjusts the LED circuit current to boost the light intensity to achieve precisely the desired Lux. Comprehensive test cases using MATLAB-Simulink is carried out to verify the performance of the proposed smart controller. Techno-economic analysis is introduced to evaluate the benefits of installing the controller. Summary and recommendation are given at the end.

Keywords: Energy Saving; Lighting Control; Smart Lighting; Green Buildings; Building Automation

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1. Introduction

According to the UN's Brundtland Commission popularized, 1987, sustainability is defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." Sustainable energy is energy that is continually available and does not harm the environment and can help improve public health. Daylight is free of charge sustainable clean energy source, and it is available for almost 12 hours daily. Efficient utilization for the daylight can reduce drastically the carbon dioxide emission and hence reduces the pollution and assist to control the global temperature rise. Additionally, daylighting creates a visually pleasing, healthier and more productive environment for building occupants. In industrial and residential applications, different technologies are being developed nowadays to utilize the daylight in electrical generation, heating process and natural indoor lighting.

A comprehensive review of daylight harvesting and methods of its control in offices and buildings is introduced in [1] [2] [3]. In these review papers, advanced daylighting harvesting systems (DHS) that are designed to maximize the energy-saving potential of day lighting, while improving comfort and visual performance at an "affordable" cost, are discussed Different study cases in theses review papers shows that energy saving potential is 20-60% comparing with non-dimmed installations, however technical robustness, architectural integration and human acceptance deserve more attention during the design and commissioning of the DHS.

The designers consider different techniques, depends on the applications, to control the DHS. Dynamic and static Shading devices are used in to optimize the power

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consumption of lighting and HVAC In [4] and [5], the use of blinds and Electrochromic windows and its economic analysis for shading the indoor spaces and hence control the heat transfer to outside for better HVAC design are discussed. In [6], the shading is evaluated using different glassing systems such as standard double-glazing system, systems with granular silica aerogel in interspace, double lazing with sunlight control films. Two remodeling methods using polymer dispersed liquid crystal (PDLC) films, which can adjust solar radiation for old office buildings are proposed and analyzed. In [7], the shading is evaluated using different glassing systems such as standard double-glazing system, systems with granular silica aerogel in interspace, double-lazing with sunlight control films. From different case studies, the paper showed that the indoor daylight Lux using achieved by standard Glazing is 500 Lux approximately.

Smart Curtains are also used widely in DHS applications. The performance of curtain wall-facades of varying designs incorporating photovoltaics opaque and semitransparent on energy performance, daylighting level for an apartment within amid-rise apartment building is discussed in [8]. Arduino is used with different sensors in [9] [10] [11]to integrate either closing or opening operation of the curtains in the control system of smart home to optimize the utilization of the daylight and to reduce the power consumption. Smart wireless control of the curtain is provided in [12] to either open or close the curtain using mobile. This intelligent curtain can work in the manual mode, automatic mode and sleep mode and can be carried out by the button and mobile phone APP mode loop switch.

Beside the scientific efforts to control the daylight for indoor economic illumination, other efforts are being spent to use and to control less cost lighting devices such as LED's in the indoor lighting for better users' satisfaction. Remotely controlled LED lighting system uses Android apps for handheld devices is discussed in [13]. In this paper, the ZigBee standard is followed to design the wireless data communication. Smart LED control systems equipped with movement sensors, brightness control and /or color temperature adjustment use different technology approaches is discussed in [14] 15] [16].

Several scientific work incorporates the utilization of the daylight in the design of the indoor lighting control. In [17], Mahmoud utilizes the background daylight as base source of the light, and then control the LED lighting system to achieve the desired value of Lux, if required. Arduino is used as a controller unit to receive the background light intensity signal from the light sensor and to adjust gradually the lighting intensity in the room to meet the desired Lux value or higher. Movement sensor is used to switch off the light in case there is nobody in the room. The proposed methodology by Mahmoud does not consider the over-Lux cases, and accepts that the light intensity in the office to be higher than the desired value if the daylight inside the room is greater than the desired Lux value. The authors in [18] use set of switches that control lighting circuits (a switch per circuit), and another set of light sensors. All these devices are integrated in one logic algorithm to utilize the daylight with the lighting circuits to adjust the light intensity in the room. The algorithm in this method, first turn off all lights and then turn on one light circuit at a time and record the light's impact, and repeats this process till the desired light intensity is achieved. This suggested method is not accurate because although it considers the daylight level in the initial calculation of the room light intensity, but it does not control the daylight level inside the room. It also does not integrate occupancy detectors in the algorithm. Also, as the method uses many switching and sensors devices, this make the method is expensive and not reliable. In [19], Suradi, - et al. proposed a system that utilizes the daylight by opening automatically the windows if the Lux setting in Arduino is between 110 Lux and 210 Lux. Arduino stops window opening process if the measured Lux is greater than 210 Lux. The window receives closing signal in case there is no daylight available. This system is not accurate in controlling the daylight intensity entering the room, and the controller has narrow range of the lighting intensity adjustment inside the room. In [20], Cruz, Renz Joseph E. et al. propose a solution for smart rooms to conserve energy in the buildings by integrating the daylight with a curtain and light appliances in one MPU controller. In this method LDR is used to control Servo motor that control the window curtain to maximize the use of daylight. However, the project failed to implement an efficient use of the daylight to maintain the light intensity level.

Techno-Economical evaluations are discussed in several articles that include direct and indirect benefits obtained from using different intelligent lighting and heating systems. In these economic analysis, "Direct benefits" are categorized in two parts; operational and maintenance cost. For "Indirect benefit", it is categorized also into two parts, more oil/gas sale opportunity and reduction of pollution [21-26].

In this article, accurate approach for the design of Indoor Lighting utilizing the daylight with LED lighting system is introduced. In this approach, adaptive dual control is used for roller blinds and LEDs simultaneously in order to minimize the power consumption of the indoor illumination system and achieve precisely the desired light intensity level.

In section II, the design of the proposed smart Lighting System is given. The proposed lighting system response and results are illustrated in Section III. Techno-Economical analysis is provided in Section IV. Finally, Section V summarizes the entire work and gives the conclusion and recommendations.

I. 2. Design of the Proposed Indoor Smart Lighting System Controller (ISLSC):

2.1 Design Criteria

As the sun is considered at infinity distance from the window, so the lighting intensity projection on the window is assumed to be uniform. Five hundred (500) Lux is considered as the average daylight intensity passing through the window when it fully open [7]. When the blind fully close, no daylight is penetrating to the room. The daylight passing the window is linearly proportional to the roller blind opening percentage.

In most indoor application the desired Lux level does not exceed 500 Lux. Table 1 illustrate the desired light intensity for indoor different application [27]:

Table 1. Design average level of illuminance for various places**.**

Facility type	Area or task type	Emin(Lux)
General	Entrance halls or corridors	100
Offices	Typing ,Writing, Reading	500
Offices	Technical drawing/Working on computer	500-750
Offices	Conference rooms/Archives	200-500
Restaurant	Kitchen/Dining room	300-500
Schools	Classrooms/Library and Laboratories	300-500
Hospital	Waiting rooms/Operating theater	200-1000
Residential	Kitchen	300
Residential	Dining Room	100–250
Residential	Living Room	200
Residential	Bedroom	150
Residential	Bathroom	200
Residential	Hallway	100–200

As this ISLSC will be installed in controlled temperature area, so the impact of temperature variation on the Lux sensor accuracy is not considered.

2.2. Component:

The proposed system composes of the following main components:

2.2.1. LDR Transducer:

Two Lux sensors based on Dependent Resistor (LDR) technology are used. LDRs or Light Dependent Resistors are very useful especially in light/dark sensor circuits. Normally the resistance of an LDR is very high. Typically, around 1000 000 ohms at 10 Lux or less. But when they are illuminated with light, resistance drops dramatically. The LDR Lux transducer device is chosen to be used in this proposed smart lighting system controller because of its high sensitivity, easy employment in the control circuit, low cost of approximately 20 USD/piece and it high light-to-dark resistance ratio. The main disadvantages are its slow response and low temperature stability. However, these disadvantages do not affect the performance of the indoor lighting control as fast response is not a concern and the indoor temperature does not go too low.

First Lux transducer must be installed near to the window to receive the daylight intensity (DT). The function of the second Lux transducer is to measure the average Lux inside the room (RT). This can be done using group of the transducers if required, in case the room area is large.

2.2.2. Stepper Motor System

The method uses stepper motor drive together with stepper motor to provides linear control position for the roller blind. The step size of the stepper-motor is 1 degree for each unit input. This is to achieve precise control for the operation of Roller blind. In this position control model, the input reference to the stepper motor drive is the desired number of steps. So if the light intensity is taken as input to the stepper motor drive, so 500 Lux is equal to 500 steps. Typical price for such fractional horsepower stepper motor including the drive and the gearbox is 50 USD approximately.

The differential equation for the stepper motor are given as bellow:

$$e_A = -K_m.\omega.sin(N_r.\theta) \quad (1)$$

$$e_B = K_m\omega.cos.(Nr_r.\theta) \quad (2)$$

$$\frac{di_A}{dt} = \frac{v_A - Ri_A - e_A}{L} \quad (3)$$

$$\frac{di_B}{dt} = \frac{v_B - Ri_B - e_B}{L} \quad (4)$$

$$\frac{Jd\omega}{dt} + D\omega = T_e \quad (5)$$

$$T_e = -K_m\left(i_A - \frac{e_A}{R_m}\right)sin(N_r.\theta) + K_m\left(i_B - \frac{e_B}{R_m}\right)cos(N_r.\theta) - T_d sin(4N_r.\theta) \quad (6)$$

$$\omega = \frac{d\theta}{dt} \quad (7)$$

Where:

e_A and e_B are the back electromotive forces induced in the two phase windings named *A* and *B* of the motor, respectively.

i_A and i_B are the *A* and *B* phase winding currents.

v_A and v_B are the A and B phase winding voltages.

K_m is the motor torque constant.

N_r is the number of teeth on each of the two rotor poles. Where, the Full step size parameter is $(\pi/2)/N_r$.

R is the winding resistance.

L is the winding inductance.

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R_m is the magnetizing resistance.
D is the rotational damping.
J is the inertia.
ω is the rotor speed.
Θ is the rotor angle.
T_d is the detent torque amplitude.

MATLAB – Simulink Stepper Motor Driver block is used to create the required pulse trains for the stepper motor presented in the above mentioned equations (1) to (7) [28].

2.2.3. Roller Blind

Motorized roller blinder for standard-size window is used to control the daylight access to the room. The cost of a blind designed for ZigBee smart home automation system is approximately 15 USD.

2.2.4 LED light system

As the objective of this article is to minimize the power consumption of the indoor lighting, therefore, LED lighting system has been chosen because of its reliability, low running cost and its linear characteristic for light intensity with the current. Most common LED's require a forward operating voltage between 1.2 to 3.6 volts approximately with a forward current rating of about 10 to 30 mA [29]. Occupancy sensor is used to switch on/off the light circuit based on the movement in the room.

2.3. Control Circuit Description:

In the proposed control circuit, first Lux transducer (DT) receives the daylight intensity. The transducer-output electrical full scale signal is 10 mA, which representing 500Lux. This electrical signal is translated back to its corresponding daylight Lux value using gain factor of 50000. The actual daylight value is compared with the desired Lux value for the room, and the error is used as reference input to the stepper motor drive to control the closing of the roller blind to allow only the desired Lux to be achieved. The second Lux transducer(RT) simultaneously measures the light intensity inside the room, and the controller compare it with desired value of Lux. If the desired lux is achieved, no further lighting will be required from the LED circuit. If the required Lux is still higher than the room Lux, then the controller will send signal to the LED circuit to increase the current, and hence adapt the light intensity, till the desired Lux is achieved. Figure 1 illustrate the Simulink circuit that is used to implement this control scheme. Arduino or any simple PLC with a cost of 50 USD can be used easily to build such Smart controller.

It is worth to mention that based on above mentioned control logic, this ISLSC is a general unit. Even if the daylight exceeds 500Lux due to the orientation of the window, minor calibration for the stepper motor drive will be required to maintain the same ISLSC works efficiently.

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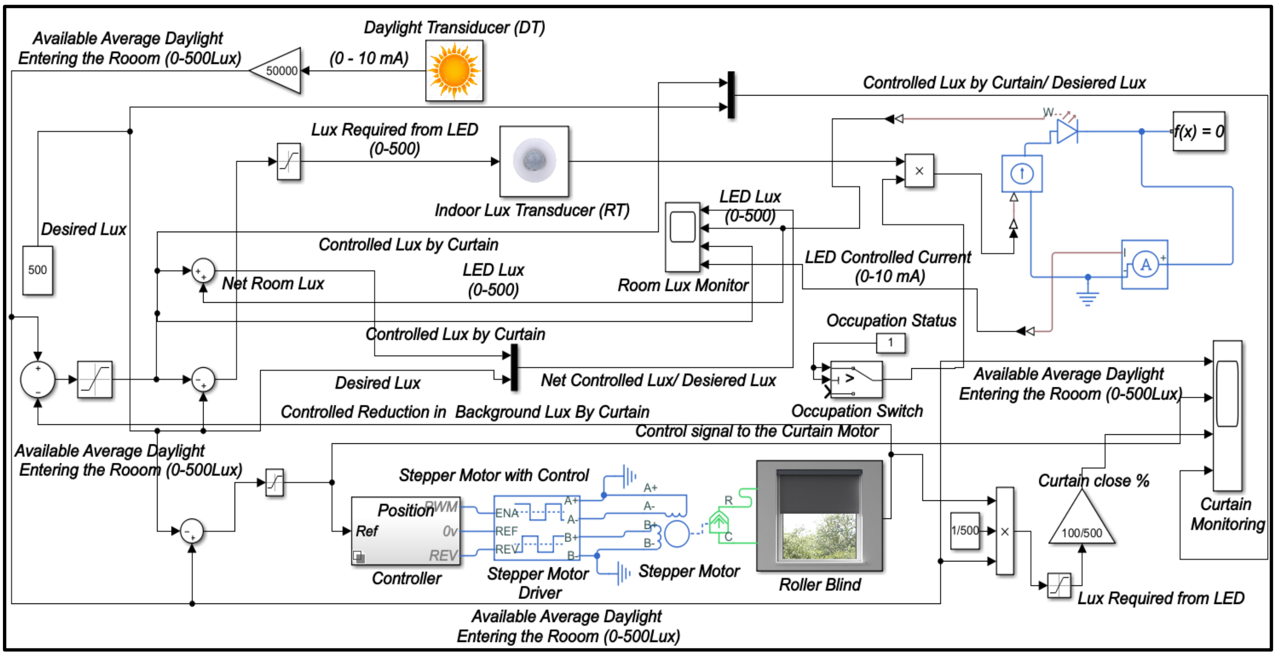

Figure 1. ISLSC Simulink circuit.

3. Response and Result:

Using the circuit illustrated in Figure 1, five study cases are carried out to verify the performance of the proposed ISLSC. These cases are selected to cover the main Lux value listed in Table 1. The value of the Desired Lux that are selected for the study cases are 100, 200, 300, 400 and 500 Lux. Figure 2 to Figure 6 illustrate the results of these five test cases.

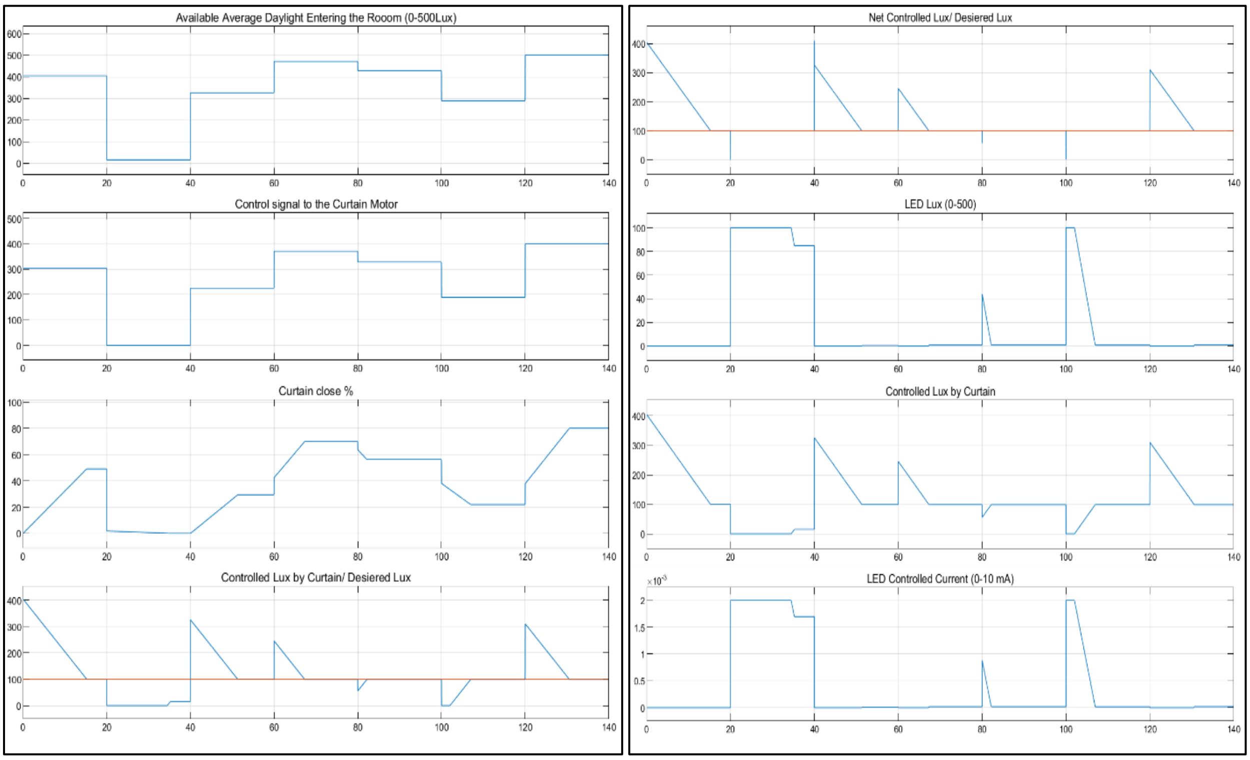

Figure 2. Results for Desired Lux = 100.

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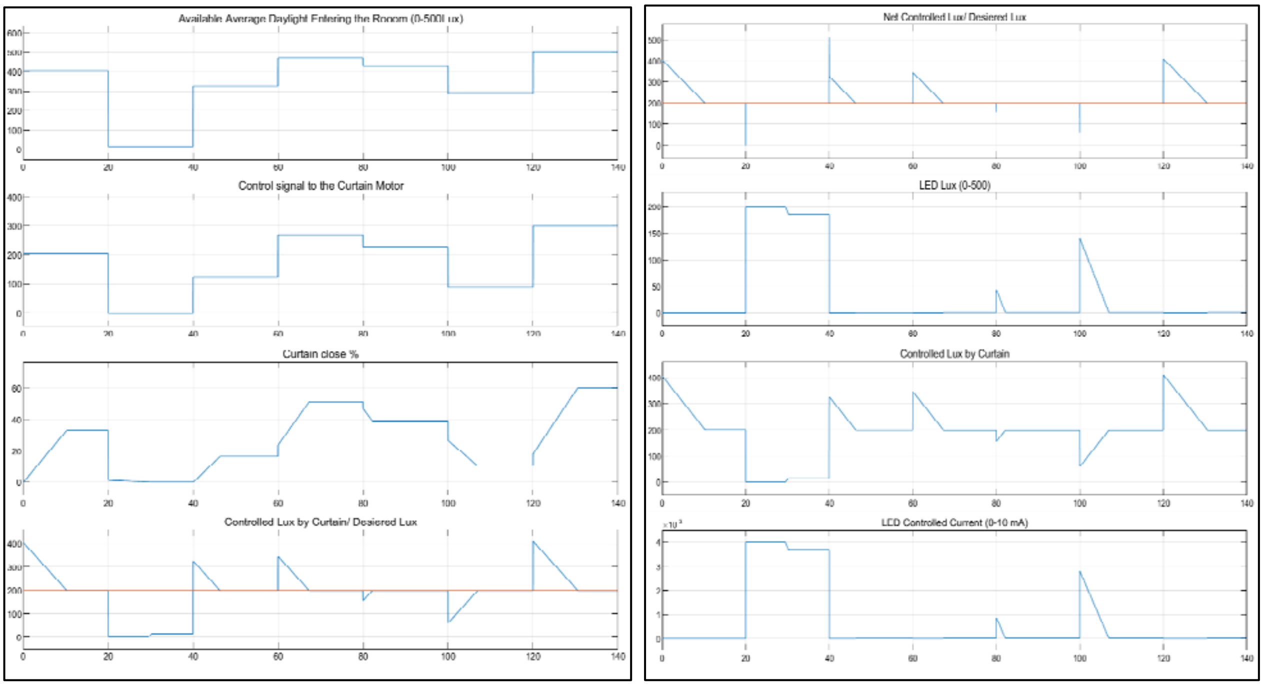

Figure 3: Results for Desired Lux = 200

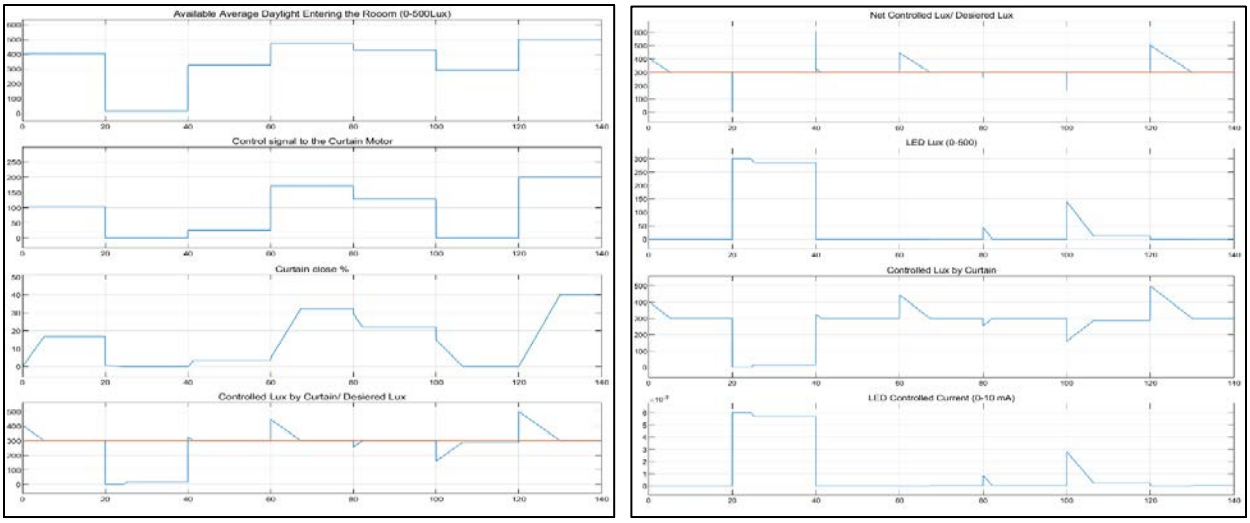

Figure 4: Results for Desired Lux = 300

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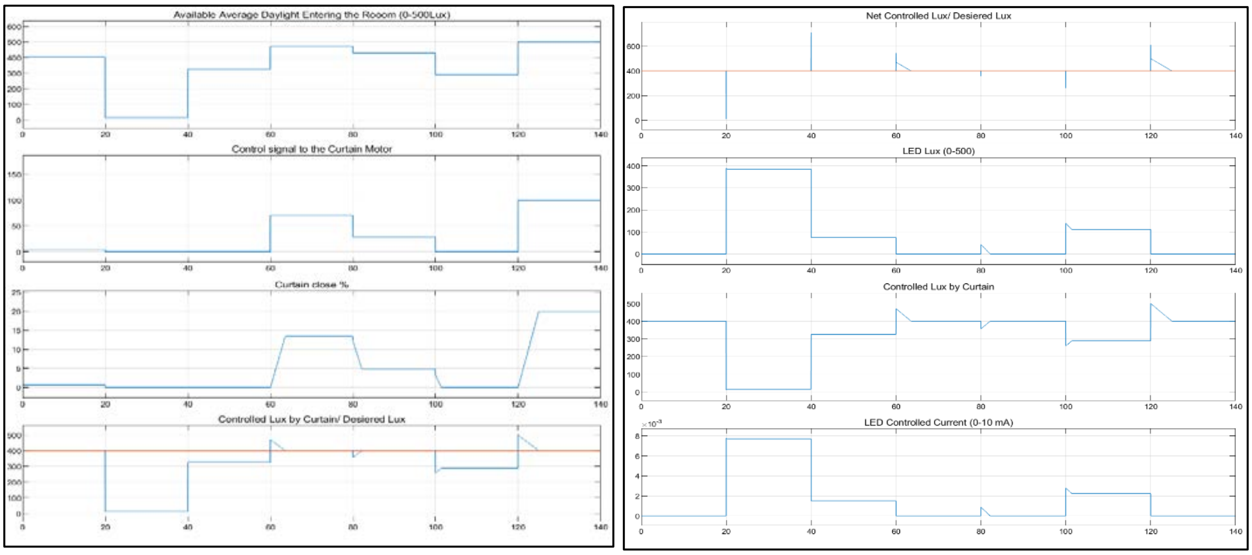

Figure 5: Results for Desired Lux = 400

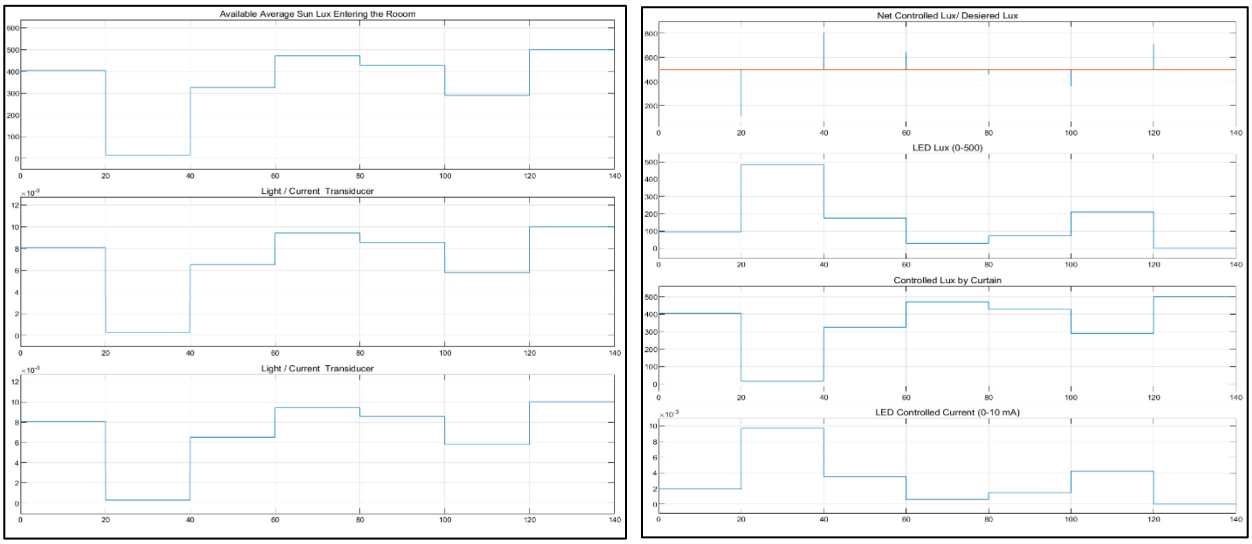

Figure 6: Results for Desired Lux = 500

From the result it can be seen that the proposed ISLSC succeeded to control the light intensity inside the room to achieve precisely the desired lux value for all the five test cases by properly controlling the daylight passing through the window and simultaneously control light that can be obtained from the LED circuit. As the priority is given to the daylight to be used to fulfil the desired lux, and if required, the LED circuit operates to compensate any further need of light to achieve the desired Lux value, therefore by this methodology, ISLSC minimizes the power consumption of the indoor lighting.

4. Economic Analysis:

As mentioned earlier, in Techno economic analysis "Direct Benefit" is categorized into two parts; operational and maintenance cost. However, "Indirect Benefit" is categorized also into two parts, introducing more oil/gas sale opportunity and reduction of pollution. The cost of this intelligent lighting system is negligible compared with other lighting systems such as cables, light fixtures, switches, conduits and installation work.

In this section, Techno-Economical evaluation is carried out to calculate the direct and indirect benefits obtained from using the proposed ISLSC in a typical indoor lighting for an office. In this case study, 14 hours starting from 7:00am to 09:pm is considered as working hour for the office. Occupancy sensor is assumed to switch on the light at 07:000

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and switch off the light at 09:00 pm. The daylight data is taken from [30]. The required indoor lighting intensity of 400 Lux is selected from Table 1 for the "Conference rooms/Archives".

In this case study, the maximum available daylight penetrates from the window is 900Lux. Therefore, minor calibration is required to adjust the roller blind to set 100%-closing position to zero Lux, and to set Zero%-closing position to 900 Lux. This can be done either from the stepper motor drive or by changing the gearbox connecting the motor to the roller blind.

This case study is modeled in Simulink using the same ISLSC discussed in Section II and III after adapting the "curtain % close "gain to match 900 Lux instead of 500 Lux. The output from this simulation is to insure that ISLSC is still working efficiently after the minor calibration, and also to calculate the energy saving and hence, evaluate the "Direct" and "Indirect" benefits that can be obtained by using the proposed ISLSC.

In Figure 7, the results of 14 hours' operation of the office is illustrated. From the graph is is clearly that the roller blind tries always to pass only the desired Lux from the daylight to the room. If the available daylight is less than the desired lux value, ISLSC resources the difference in the Lux from the LED circuit to maintain the lighting intensity 400 Lux all the time. The result shows efficient and fast performance of the ISLSC. The spicks in the graph are due to the sudden change of the daylight level, which is not there in the real situation. Therefore, more smooth lighting control is expected in real application.

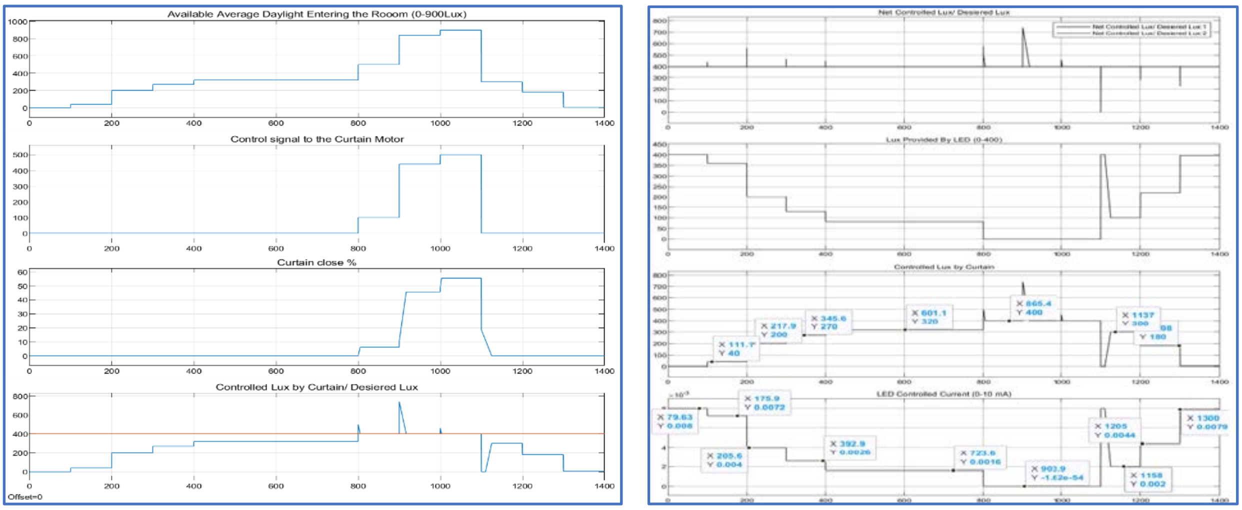

Figure 7: Lighting Operation of 14 hours with maximum 900 Lux daylight and 400 Lux Desired value.

4.1. Direct Benefit:

- Power Consumption Saving %:

In Direct Benefit for the indoor lighting of the office using ISLSC, the comparison of the power consumption takes into consideration the illumination of the office with, and without, using the ISLSC. Power consumption saving percentage is evaluated from the results obtain in Figure7 by calculate the daylight contribution from area under the "Controlled Lux by Curtain" curve, and refer it to the desired Lux calculated from the area under "Net Controlled Lux/ Desired Lux", ignoring the spics areas, as following:

$$Power\ Consumption\ Saving\ \% = \frac{Daylight\ Contribution}{Desired\ Lux} * 100\% \qquad (8)$$

$$\text{Power Consumption Saving } \% = \frac{0 + 40 + 200 + 270 + 4 * 320 + 3 * 400 + 300 + 180 + 0}{14 * 400} = 61.96\ \%$$

- LED Circuit Maintenance Saving:

During operation, LEDs luminous flux gradually decrease due to aging, meas. In general, this aging is affected by different factors such as the operating current, voltage, temperature and humidity. Figure 8, from Osram, illustrates the degradation curve of LED light with time [31]. A power LED industry group, the Alliance for Solid-State Illumination Systems and Technologies (ASSIST), found that 70% lumen maintenance is close to the threshold at which the human eye can detect a reduction in light output Driving the LED at a level below its maximum rated forward current will extend its useful lifetime, thereby increasing the quotable L70 and L50 lifetimes [32].

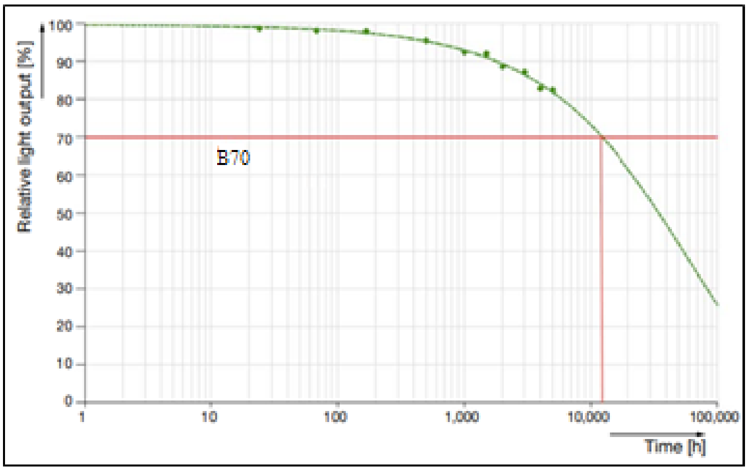

Figure 8: Lifetime Degradation

Analyzing the above LED lifetime degradation curve, it can be seen that the LED lifetime can be considered 12000 hours approximately to give the required luminous flux (Lumens) with satisfaction human eye. Using ISLSC can extend allow to use the same LED Fixture with lower luminous flux for some extra time without disturbing the human eye. Figure 9, illustrates a case study that limits LED luminous flux to 50% for further analysis.

By recalling that the value of the "Desired" lighting intensity for the office is 400 Lux, and 70% of this value is 280 Lux, so, the net lux in the room can go down to 280 Lux without disturbance of the human eye. The result of Figure 9 shows that the lighting intensity remains above 280 Lux for 12 hours, and above 200 Lux (50%) for only 2 hours. This result is very acceptable and increases the utilization lifetime of the LED circuits 300%. This means the maintenance cost can be reduced by one-third using ISLSC assuming that the LED circuit are operated at its rated current.

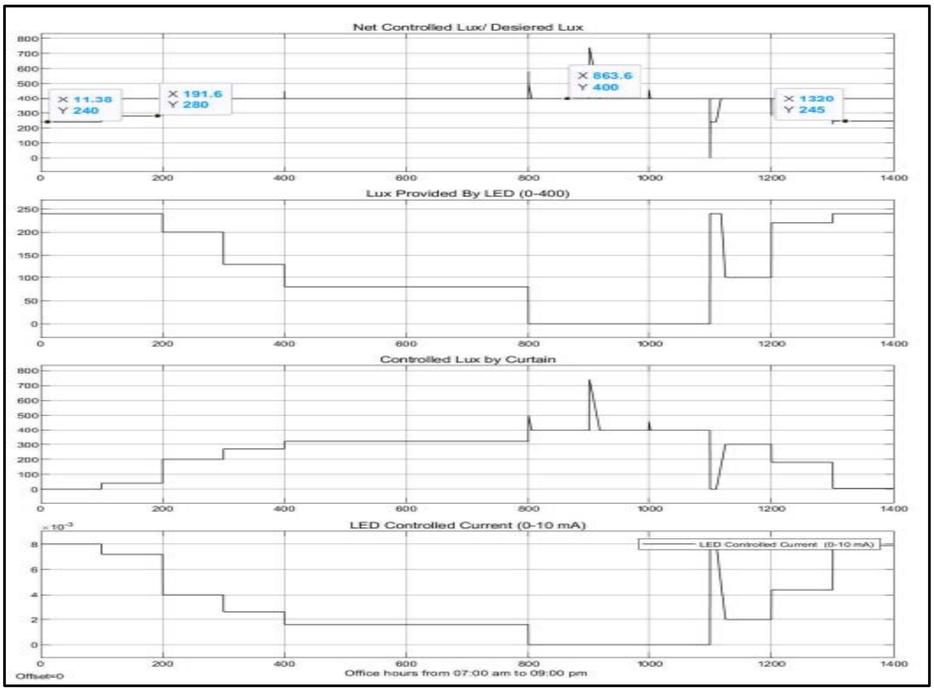

Figure 9. Lifetime Degradation.

From another direction of the LED lifetime evaluation, as per ASSIST the temperature of the LED junction also influences lumen maintenance: designing for a lower junction temperature will extend the L70 and L50 figures for the LED. For this reason, thermal design considerations are an important aspect of designing an LED-based lighting system. Accordingly, driving the LED at a level below its maximum rated forward current generates less heat in the LED and hence extend its useful lifetime, thereby increasing the quotable L70 and L50 lifetimes. Figure 10 illustrates the lifetime of an LED at different loading.

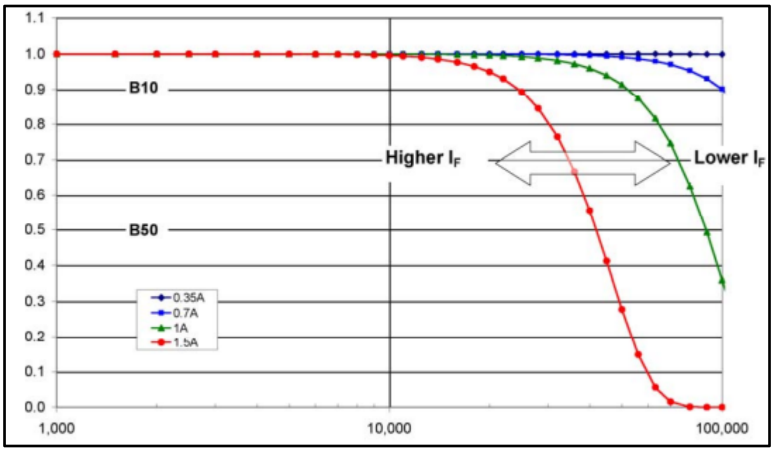

Figure 10. The effect of forward current value on the useful lifetime of an LED

To evaluate the LED lifetime due to the operating current reduction, daily average current reduction percentage is calculated using Figure 8 as following:

$$Daily\ Avverage\ Current\ reduction\% = 100 - \frac{Average\ current\ consumed\ in\ 14\ Hrs}{LED\ full\ load} * 100\ \% \quad (9)$$

$$Daily\ Avverage\ Current\ reduction\ \% = 100 - \frac{0.008+0.0072+0.004+0.0026+4\times 0.0016+3\times 0+0.002+0.008}{0.008} = 65.89\%$$

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Using Figure 10 to estimate the new LED lifetime corresponding to 34.1 % current loading, the graph shows that the LED will have more than 100,000 hours' lifetime. This result gives approximately 20 years' lifetime for the LED if ISLSC is used.

Based on the above two analyses, by using ISLSC and except of normal cleaning for the light Fixtures, the LED circuits will not require any maintenance as long as it is operated within its operation conditions.

4.2. Indirect Benefits:

- Annual Gas Sale Opportunity

By saving the energy consumed in the indoor lighting system by using ISLSC, country can export larger amount of gas. The average value for gas selling price during the last 25 years is $ 4.17/MMBtu on the basis of US Energy Information Administration Henry Hub/NYMEX, natural gas valued spot price, Figure 11 [33].

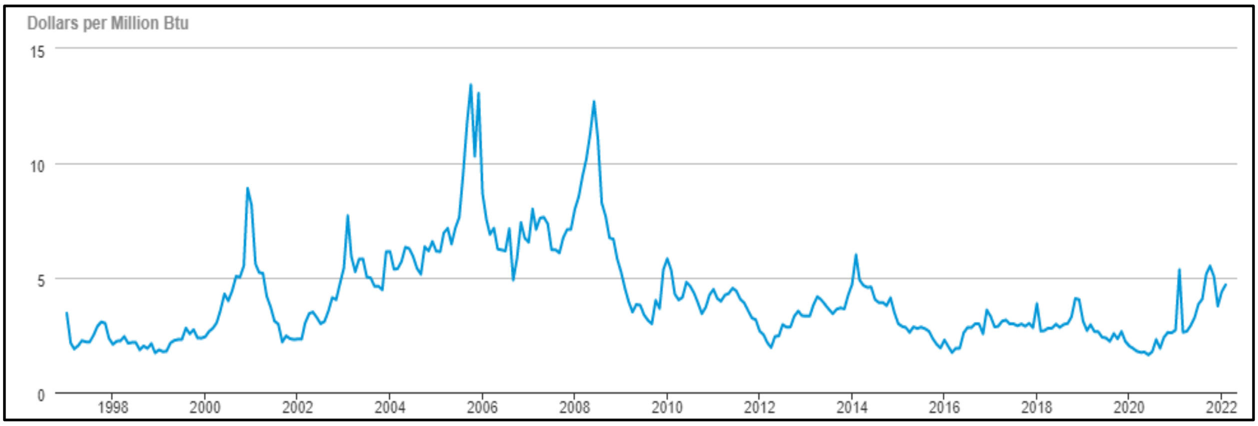

Figure 11. Henry Hub Natural Gas Spot Price

The equivalent energy rate is 0.014228 $/kWhr (thermal) is used in eqn. (10) to estimate the annually sales opportunity for the natural gas that can be by obtained by using ISLSC in a building has 100 standard office with 20 m^2 area each:

Power consumption for one office to achieve 400 Lux from LED circuits is approximately 144 Watt. Using ISLSC, the saving in power consumption based on the calculated saving percentage value in eqn (8) is 89 .22W. For 100 office the total saving in power consumption is 8.922kW.

For stand-alone gas turbines, the average turbine efficiency is 35% approximately [34]. So the thermal converted saving power is 25.5kW approximately and the annual energy thermal saving considering 14 hours operating time is 130,262 kWhr (thermal).

$$Annual\ Natural\ Gas\ Sale\ Opportunity = 0.014228 \times Thermal\ Energy\ saving = 1{,}853\ \$ \quad (10)$$

This result is encouraging to install the proposed ISLSC in as many as possible indoor LED circuits to maximize the gas sale opportunity that can achieved from the reduction of power consumption in indoor lighting.

- Annual Saving in Pollution

Second indirect benefit is related to the pollution and hydrocarbon gases emitted from power generation plants to produce electrical power. Carbon credits based on EU Emissions Trading System hit 31 euro/ton Figure 12 [35]. Where, CO_2 emission is considered to be 0.83 kg/kWh. Assuming Euro to USD exchange rate of 1.2, by using the proposed ISLSC the annual saving in pollution reduction can be calculated as following Eqn. (11) [36]:

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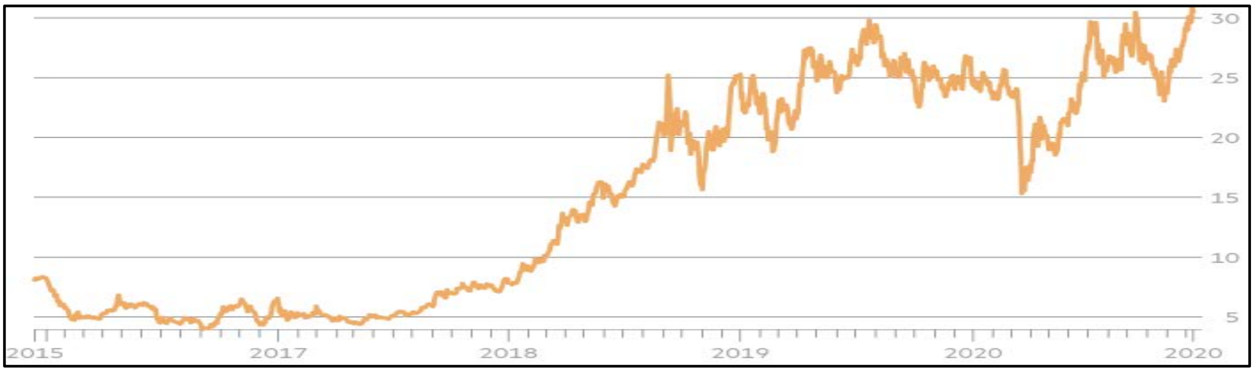

Figure 12: The price on the EU Emissions Trading System hit above €31

$$Annual\ Saving\ in\ Pollution = \frac{0.83 * Thermal\ Energy\ saving * 1.2 * 31}{1000}\$ \quad (11)$$

Thermal energy saving of 130,262 kWhr was calculated for 100 standard office with 20 m^2 area each. This value is used to estimate the annual saving in pollution using eqn (11). This gives saving of additional approximately 40,22$ in the Indirect Benefit.

It is useful to calculate the Annual Indirect Benefit Saving Index (AIBSI) for standard office as following

$$AIBSI = \frac{Annual\ Natural\ Gs\ Sale\ Opertunity + Annual\ Saving\ in\ Pollution}{(Number\ of\ Offices)} \quad (12)$$

$$AIBSI \ = \ 58.75\ \$/Office/Year$$

This AIBSI index is very encouraging to standardized the proposed ISLSC to be installed with any indoor LED lighting system because of its contribution in global temperature rise solutions. Also, it is important for project managers use such index to evaluation the cash flow, maintenance requirements, and budget decisions.

5. Conclusion

On average, lighting costs account for one-third to one-half of a building's total electricity costs. Effective daylight distribution through reflection and diffusion can reduce electric lighting power costs and improve the usefulness of natural light. In this article, efficient Indoor Smart Lighting System Controller (ISLSC) was proposed to control simultaneously the LED circuit current and the roller blind position, that is driven by stepper motor, to adjust the indoor lighting intensity to meet the desired preset Lux value. Different test cases were carried out to prove the controller performance precision. The test showed that ISLSC succeeded to maintain the indoor lighting intensity at the desired lux level. The test showed also in case ISLSC is used to control the lighting intensity in different room with different daylight condition, only minor calibration will be required, and then the ISLSC will be ready to function under the new condition.   Based on this flexibility in the design, the ISLSC can to be installed for windows at all four directions regardless the daylight level or its angle. In general, the greatest benefits of daylighting result from maximizing a building's northern and southern windows while minimizing its eastern and western windows. Northern and southern lighting is easily controlled. Northern light is relatively diffuse, with little glare, and often does not require the use of external shading. Southern daylight is abundant, with more opportunity to direct lighting deeper into the room, but glare must be controlled to manage this opportunity. However, although windows to the east and west, as well as unshaded southern windows, can cause excessive glare due to low sun angles and excessive cooling loads due to difficulty in shading, but using ISLSC with selected correctly roller blinds, that can reflect-back some solar energy

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to outside through the glass, can reduce this glare and cooling load because only the required daylight is allowed to penetrate into the room. Glare can be further reduced if light diffuser glasses for the window is used and it is very suitable to work with ISLSC.

Comprehensive techno-economic analysis is introduced to calculate the “Direct Benefit” and “Indirect Benefit” that can be obtained from the installation of the proposed ISLSC. From the analysis it was found that in “Direct Benefit”, energy saving of approximately 62 % can be achieved, and the LED circuits lifetime can extend to more than 20 years. In “Indirect Benefit” saving index was calculated combining the two “Indoor Benefit” categories in one indictor number. "Indirect Benefit" index showed saving of 58.75$/Office/Year, this figure is very useful to managers in taking their decisions. Based on the encouraging value that is calculated by this index, it is recommended that the proposed ISLSC to be installed in all indoor lighting types, not only LED circuits, after minor modification, if required.

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