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LIGHTING – THE WAY TO REDUCING ELECTRICAL ENERGY DEMAND IN UNIVERSITY BUILDINGS IN BANGLADESH

Md. Yousuf Ali, Imran Khan, Mehedi Hassan

Department of Electrical and Electronic Engineering,
Jashore University of Science and Technology, Jashore-7408, Bangladesh

Abstract. *Lighting is one of the dominant electricity demand factors in the building energy sector and has huge potential for demand reduction. However, concerning the efficacy of energy consumption, this potential energy-saving option entails further investigations, particularly for developing countries. This study addresses the issues of an efficient lighting system design for educational institutions with particular attention to classroom and laboratory lighting systems for a university in Bangladesh as a case study. Measurements show that during the daytime, under clear and average sky conditions both rooms received sufficient natural light (>300 lx) for educational activities, whereas under an overcast sky, only 50% space receives sufficient natural light. At night, the installed fluorescent tube lights illuminance level was found insufficient (<300 lx) for educational activities. The inefficient lighting system design was found to be the main reason for this illuminance level. Simulation results reveal that light emitting diode (LED) tube lights with a maintenance factor of 0.8 could save 10,080-15,120 kWh, 91,929-137,894 BDT (1USD=84BDT), and 6,753-10,130 kgCO_2-eq, energy, cost, and, greenhouse gas emissions respectively per year for the classrooms.*

Key words: *Lighting efficiency, Electricity demand, Energy saving, Lighting system design, Lighting energy demand.*

1. INTRODUCTION

Lighting is responsible for system peak demand in both developed and developing countries. For instance, it was found that about 12% of demand was attributed to evening peak lighting in winter in New Zealand [1]. Thus, reducing energy demand from lighting could be beneficial for electricity authorities. Lighting demand could be managed in three different ways: (i) use of ‘new more efficient equipment’, (ii) ‘utilization of improved lighting design practices’, and (iii) ‘improvements in lighting control systems to avoid energy waste for unoccupied and daylight hours’ as identified in [2]. The focus of this

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Corresponding author: Imran Khan
Department of Electrical and Electronic Engineering, Jashore University of Science and Technology, Jashore-7408, Bangladesh.
E-mail: ikr_ece@yahoo.com, i.khan@just.edu.bd

study is the second option, that is, to explore the potential of efficient lighting system design for university buildings, focusing on Bangladesh as a case study.

Lighting systems in educational institutions have significant impacts on learners' cognitive performance [3] and emotional behavior [4]. In educational institutional lighting systems at universities, about 42% of electricity is consumed for lighting purposes only [5]. One study showed that significant amounts of energy, cost, and indirect greenhouse gas (GHG) emissions could be reduced if the existing fluorescent lamps were replaced with more efficient ones in the University of Malaya [5]. Martirano (2011) proposed two different smart controls, namely switching and dimming, for the lighting systems in two classrooms in the University of Rome, Sapienza, to save energy, cost, and to increase the efficiency of the overall system [2]. In Sweden, the effectiveness of the lighting control system in an educational building in Lund was investigated and they found that about 30% of the total lighting energy consumption was responsible for standby energy use and in extreme cases, this could be as high as 55% [6]. A recent study in Greece found that through direct current light emitting diode (LED) and daylight harvesting systems, annual lighting energy consumption could be reduced from 90.5 kWh_P/m^2 to 0.55 kWh_P/m^2 for a typical classroom in a public school [7]. An energy audit for two BRAC university buildings in Dhaka, Bangladesh, found that 28% to 45% energy reduction is possible if the existing lighting systems could be replaced by more efficient ones [8].

The government of Bangladesh provides subsidies in electricity sector because the cost of electricity increases significantly during system peak hours [9]. Studies shows that there are many factors responsible for this peak demand, such as the number of occupants, use of rice cookers, and air conditioners [10]. One of the major contributors to the evening peak demand in Bangladesh is lighting [11]. The lighting load is one of the potential demand driving factors in educational buildings [5], and reducing this demand would be helpful for the grid and GHG emission reductions due to electricity generation [12].

The Energy Efficiency and Conservation Master Plan (EECMP) of Bangladesh estimated the potential of 1,862 GWh per year energy saving from lighting load in the country [11]. The plan indicates that the use of more efficient lights such as LED would be helpful to achieve this energy saving. The present lighting energy consumption of about 15% would be reduced to 7.5% [11]. However, how much energy that could be saved from educational institutions has not been identified, and this is essential in order to identify the potential energy saving from this sector. Thus, the main goal of this study is to reveal the limitations, scope, and potential of energy saving options from efficient lighting system design in an institutional building in one of the least developed countries. This study has taken into account the Jashore University of Science and Technology (JUST) campus in Bangladesh as a case study. More specifically, it considers efficient lighting system design for the classrooms and laboratories of JUST academic buildings, taking into account natural and artificial lighting along with many other parameters, such as reflectance factors.

This study is novel for a number of reasons: first, for the authors, this is the first study that has explored the potential of efficient lighting system design for educational institutions in Bangladesh, a least developed country. Although the study particularly focused on Bangladesh as a case study, the findings could be applicable to other developing countries. Second, this study reveals the limitations of educational lighting system design in least developed countries.

2. DATA AND METHOD

For this analysis, practical lux in the rooms was measured using Luxmeter UNI-T UT383 [illuminance measurement: 0-199999 Lux ± (4%+8); resolution: 1 Lux; sampling rate: 2/s][1]. At the same time, the simulation was conducted using DIALux evo 8.2 software. Although there are many software available for lighting simulation (e.g., RELUX, BTwin), DIALux evo 8.2 software was used for the simulation as it was found to be an effective tool in designing an efficient lighting system with the help of a complete database [13]. This software is able to take into account both natural and artificial lighting for simulation purposes. Many previous studies also used this lighting simulation software such as [14], [15].

The methodology used for this study is illustrated by the following sequence of events:

(i) The test room measurements are taken into consideration to develop the grid dimensional frame for measuring the lux of the rooms.
(ii) The lux of the test rooms is measured experimentally at the pre-defined grid positions through the luxmeter.
(iii) With the same room-measurements, the software tool DIALux evo 8.2 is used to measure the lux of the test rooms.
(iv) The step-(ii) and (iii) are repeated further for different lighting conditions (i.e., clear sky, overcast sky, average sky, and at night).
(v) Finally, the simulation results and the measurement samples are computed, compared, and analyzed to design an effective lighting system.

The classroom (room#836) and laboratory (room#837) in the academic building are measured and the positions of the doors and windows are properly identified. The grid dimension of the measurement samples is considered to be 1.5 m to 1.5 m with a measuring-plane height of 0.8 m, satisfying the EN 12464-1 standard [16].

For every sample, the measurement procedures are almost instant and take approximately 30 minutes to complete the total measurements. Hence, lighting conditions are nearly stable for the sample values. For the simulation, this measurement data is utilized. Using the luxmeter, lux is measured at different positions in these rooms under different natural lighting conditions, such as clear sky and overcast sky [17]. According to [18] these lighting conditions are:

- Clear sky: '*Clear sky varies according to the altitude and azimuth of the sun, is brighter and closer to the sun and attenuates when moving away from it. The brightness of the horizon is between these two extremes*.' That is a cloudless sky. The measurement is taken on 14th September 2019 at 1 pm local time.
- Overcast sky: '*this type of sky is completely covered by clouds and the view of the sun is completely impeded. Under a very overcast condition, there is little to no direct lighting and the values of global and diffuse illuminance are very close*'. For this weather conditions, we considered a cloudy day, i.e., 24th September 2019 at 1:44 pm (local time).

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[1] https://www.uni-t.cz/en/p/luxmeter-uni-t-ut383 (accessed on 12-Jun-2020)

- Average/intermediate sky: '*this is a type of sky found between the clear and the overcast skies*.' That is average weather conditions. The lux is measured on 17th September 2019 at 1 pm (local time).
- At night: No natural light is present at this condition. This measurement is taken on 17th September 2019 at 7:10 pm local time.

Finally, all these measured and simulated results are compared and the factors that have an impact on illumination are identified.

This is to be noted that the specific dates and times mentioned above are merely considered for capturing suitable measurement samples under different lighting conditions with diverse weather. At the same time, the computations are also performed with relevant samples measured at level 7 of the academic building. The geometric properties of the test-rooms (classroom and laboratory) along with the technical specifications of the luminaries are given in Table 1.

For an efficient lighting system design simulation, we used LED tube light (Philips-LL512X 1xLED50S/835 NB) and compared it with fluorescent tube light (Philips-TCS460 1xTL5-32W HFP D8-VH). For both the cases, the power of the luminaries is found to be 6.5 W/m^2. This comparison is made, as LED is becoming popular nowadays due to its low energy consumption, although most of the existing lights in university campuses in Bangladesh are fluorescent tube lights. The detailed technical specifications for these two lights are also provided in Table 1. For all the artificial lighting simulation we used a maintenance factor (MF) of 0.8. The MF is a product of different parameters as shown in Eq. (1). For further details of each of the parameters see [19].

$$MF = LLD \times LDD \times AFT \times OF \times SVV \times BF \times FSD \tag{1}$$

Where, MF = Maintenance Factor, LLD = Lamp Lumen Depreciation, LDD = Luminaire Dirt Depreciation, AFT = Ambient Fixture Temperature, OF = Optical Factor, SVV = Supply Voltage Variation, BF = Ballast Factor, FSD = Fixture Surface Depreciation.

Another crucial parameter in lighting system design is the reflectance factor. It is defined as, '*the ratio of the flux actually reflected by a sample surface to that which would be reflected into the same reflected-beam geometry by an ideal (glossless), perfectly diffuse (Lambertian), completely reflecting standard surface irradiated in exactly the same way as the sample*[2]. In general terms, it is a measure of usable visible reflected light that is reflected from different surfaces in a room when illuminated by a light source. For this simulation, the reflectance factors for the laboratory were considered to be ceiling 50%, walls 75%, and floor 50% and for the classroom, these were ceiling 50%, walls 65%, and floor 50% (based on the color of the surfaces) [20]. Note that the reflectance factors of the surfaces should be chosen carefully as the simulation result will be different with variations in this factor.

[2] https://www.ies.org/definitions/reflectance-factor-r/ (accessed on 18-Jun-2020)

Table 1 Test-room properties and technical specifications of light used for the simulations.

Test-room properties		
Type	Classroom	Laboratory
Level	L-7 (Room#836)	L-7 (Room#837)
Geometry	Floor area: 88 m^2	Floor area: 44 m^2
	Floor to ceiling height: 3.5 m	Floor to ceiling height: 3.5m
Glazing	Area: 28 m^2	Area: 14 m^2
	Orientation: South West	Orientation: South West
Fabric	Floor: Concrete	Floor: Concrete with plastic floor mat
	Wall: Plaster wall with paint	Wall: Plaster wall with paint
	Ceiling: Concrete with paint	Ceiling: Concrete with paint
Technical specifications of light used for the simulations		
Lamp Parameters	Lamp Model	
	Philips- LL512X 1xLED50S/835 NB	Philips- TCS460 1xTL5-32WHFP D8-VH
Lamp Flux (lm)	4700	3250
Total Flux (lm)	4693	2920
Luminous Efficacy (lm/W)	130	81
Correlated Color Temp. [CCT](K)	3000	3500
Color Rendering Index [CRI]	99	80
Light Output Ratio [LOR] (%)	100	90
Total Power (W)	36	36
Lamp Type	 Baten type	 Baten type

3. RESULT AND ANALYSIS

According to the Bangladesh National Building Code (BNBC), the illuminance level in classrooms or laboratories should be at least 300 lx[3]. The measured illuminance levels at different positions in the classroom for different natural lighting conditions are shown in Fig. 1. There are 16 luminaries in the classroom and 8 luminaries in the laboratory. They are uniformly placed at a longitudinal distance of 3 feet and a breadthwise distance of 8 feet from each other [21]. Except for the overcast sky and at night, the other two natural lighting conditions are more than sufficient for the classroom. On the other hand, for the overcast sky lighting condition, half of the classroom receives sufficient natural light and the other half requires artificial lighting [see Fig. 1 (c)]. Notably, at night, the existing lighting system is unable to provide sufficient illuminance levels to provide for reading or writing activities [see Fig. 1 (d)].

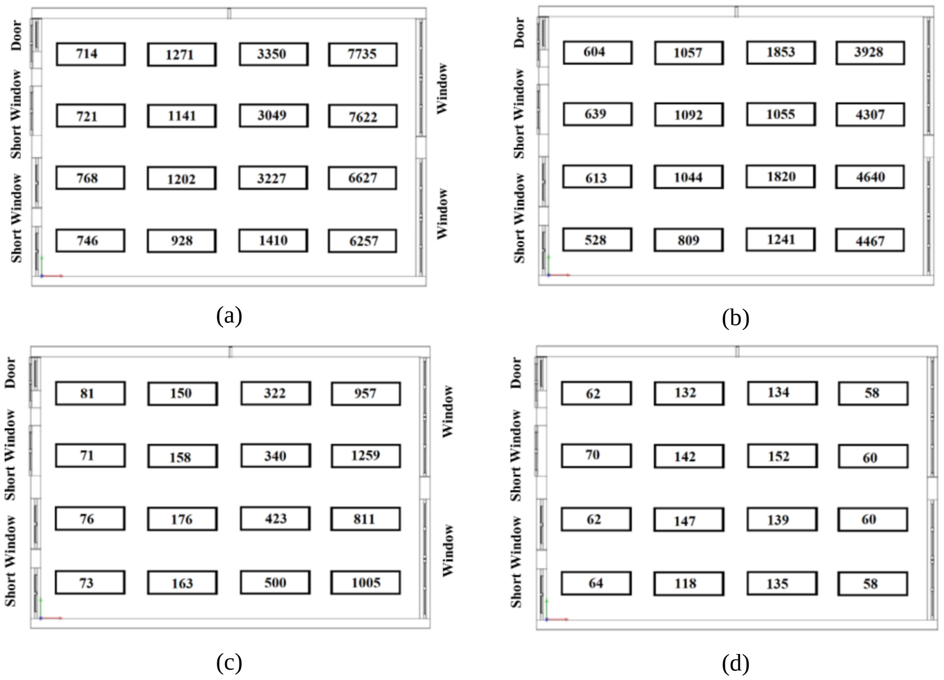
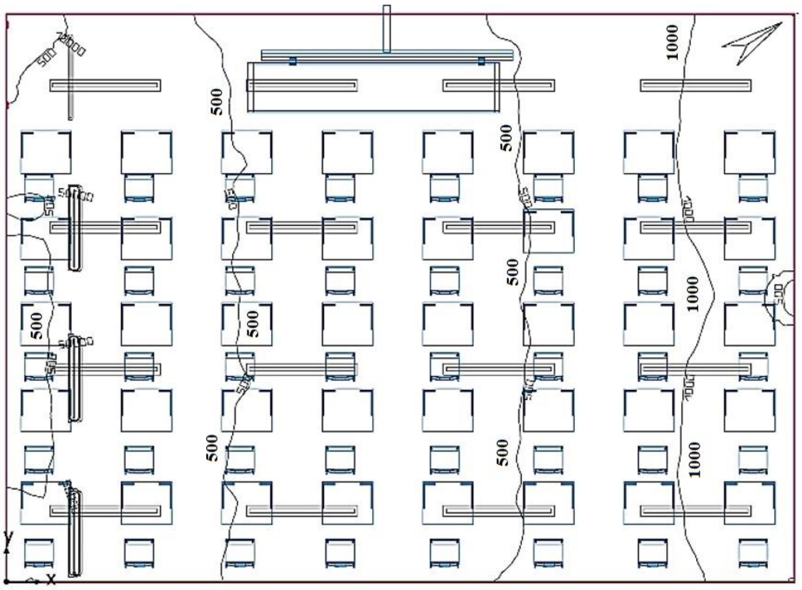


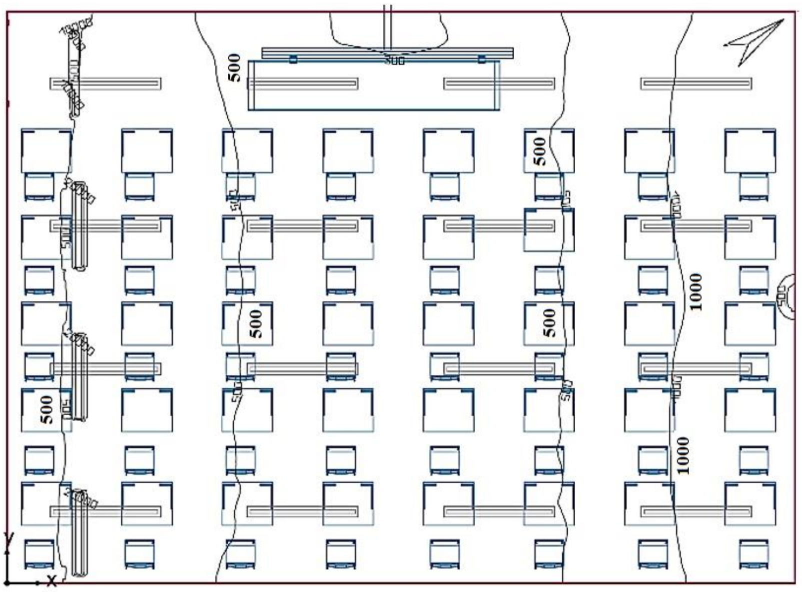
Fig. 1 Measured illuminance level in the classroom at different positions for: (a) clear sky, (b) average sky, (c) overcast sky, and (d) at night (fluorescent tube light was used).

Although the simulation results for clear sky and average sky lighting conditions show sufficient light in the classroom, the illuminance level varies from the measured values as evident from Figs. 1 and 2. One of the reasons might be the maintenance factor (MF), which is a combination of many different parameters as shown in Eq. (1).

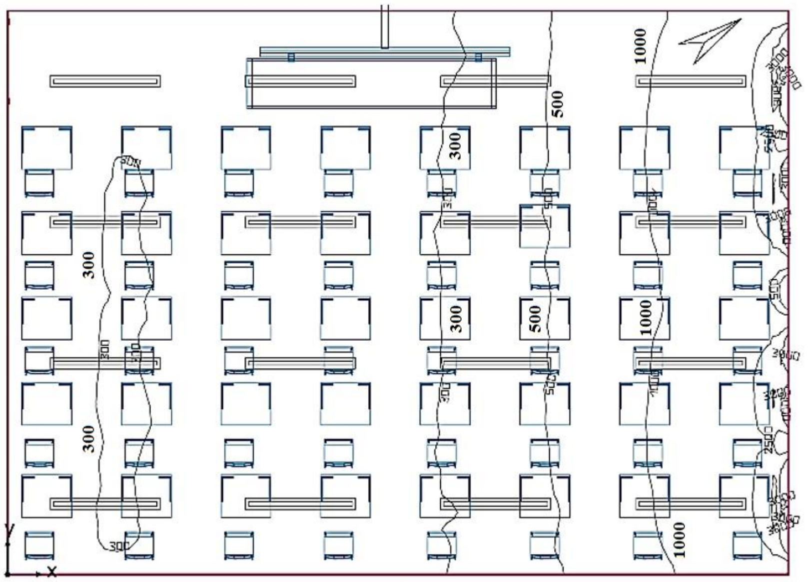
[3] http://www.dpp.gov.bd/upload_file/gazettes/39201_96302.pdf (accessed on 14-Nov-2021)



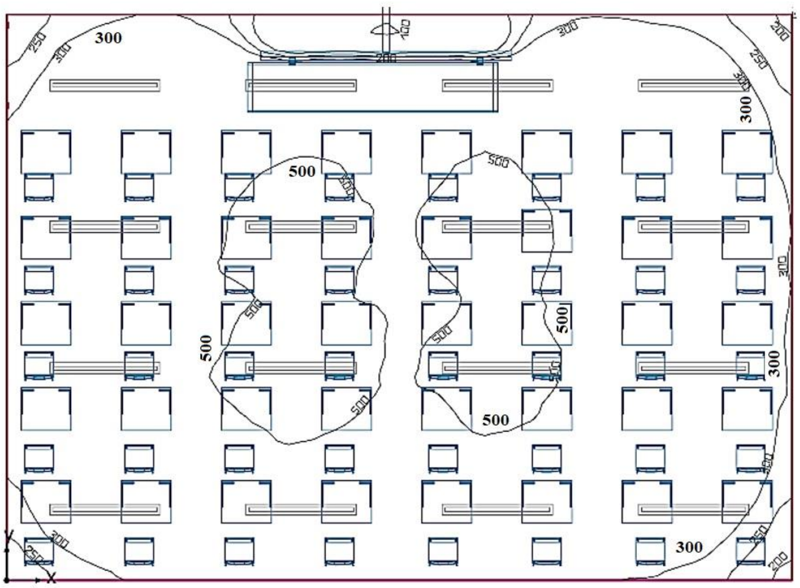
(a)



(b)



(c)



(d)

Fig. 2 Simulated illuminance level for the classroom at different positions for: (a) clear sky, (b) average sky, (c) overcast sky, and (d) at night [Philips-TCS460 1xTL5-32W HFP D8-VH].

For the overcast sky condition, the simulation results are partially in line with the measured values, particularly for the window side. The reason might be the position of the classroom. In particular, the window side is completely open and receives sufficient natural light, but the opposite side does not. A corridor and other rooms are situated on this side of the room. Thus, the measured light (through luxmeter) shows the actual scenario, whereas the simulation result shows theoretical value.

In terms of night lighting simulation, the result shows sufficient light (≥300 lux) but in actual measurement, it varies significantly. This variation is predominantly due to the use of poor-quality tube lights in the classroom, whereas in our simulation, we used Philips-TCS460 1xTL5-32W HFP D8-VH light, which is suitable for first class lighting with a clean, distinctive design. A similar result was also obtained for the laboratory as depicted in Figs. 3 and 4.

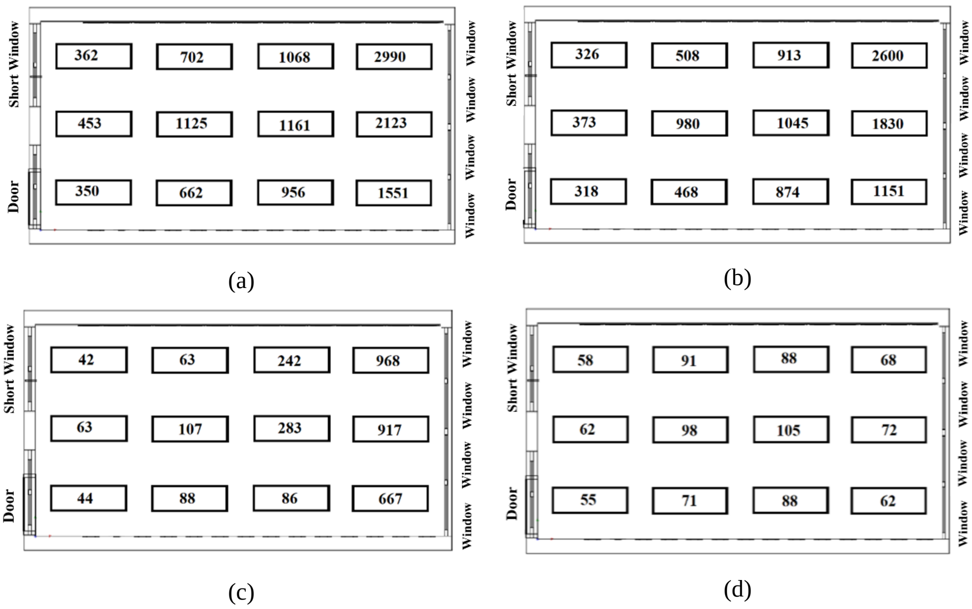


Fig. 3 Measured illuminance level in the laboratory room at different positions for: (a) clear sky, (b) average sky, (c) overcast sky, and (d) at night.

During the overcast sky and at night the classrooms and laboratories require artificial lighting. At the same time, the measured illuminance levels in both rooms indicate that the lights used are not efficient as typical tube lights with ballasts. A more efficient lighting system would be designed with LED tube lights.

Fig. 4 Simulated illuminance level for the laboratory room at different positions for: (a) clear sky, (b) average sky, (c) overcast sky, and (d) at night [considering Philips-TCS460 1xTL5-32W HFP D8-VH].

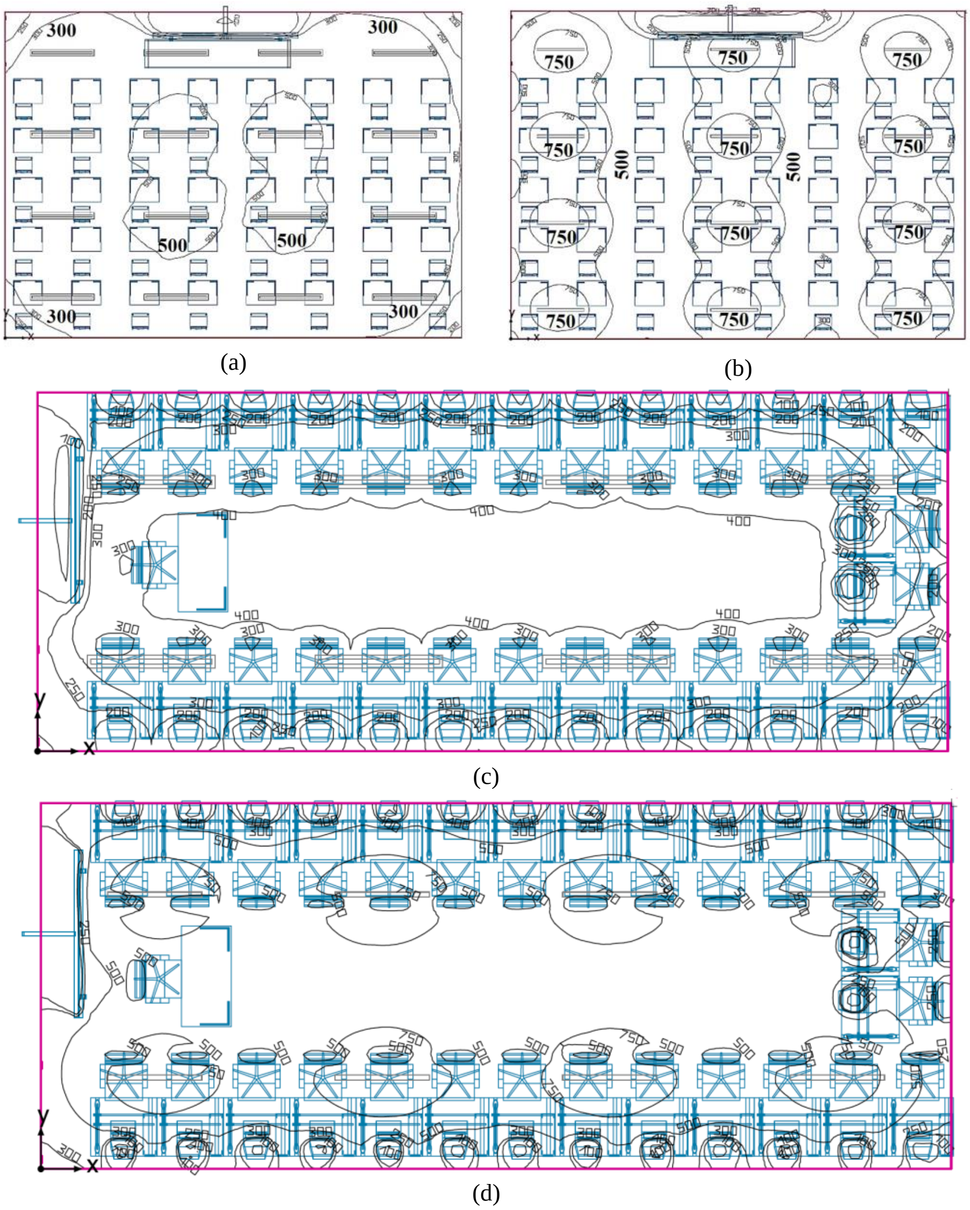


Fig. 5 Simulated illuminance level for the classroom with: (a) 16 typical tube lights, (b) 12 LED tube lights, and laboratory room with (c) 8 typical tube lights, and (d) 8 LED tube lights. Here, typical tube light: Philips-TCS460 1xTL5-32W HFP D8-VH and LED tube lights: Philips-LL512X 1xLED50S/835 NB.

Evidently, if 12 LED tube lights were used instead of 16 regular tube lights, the illuminance level that could be obtained from the former is better than the latter for the classroom [see Figs. 5 (a) and (b)]. Although the number of LED tube lights could not be reduced for the laboratory, the illuminance level improved significantly from the illuminance level with typical tube lights [see Figs. 5 (c) and (d)].

It can be seen from Table 2 that the cost of LED light is higher than typical tube lights. However, about 25% of energy and cost-saving can be achieved from this LED lighting system compared with typical tube lighting for the classroom. The average illuminance level was increased by 115 lx. In contrast, no energy or cost-saving was observed for the laboratory. Nonetheless, with an extra expenditure of 1,840 BDT, an additional 239 lx was achieved.

Table 2 Cost-benefit analysis

Sl. No.	Type	LED Tube Light	Typical Tube Light
		For Classroom	
1.	Price (BDT*)	350 (average unit price- only for light) 350×12 = 4,200	120 (average unit price-only for light) 120×16 = 1,920
2.	Average illuminance level (lx)	535	420
3.	Energy consumption (kWh/year)	520-830	700-1,100
4.	Energy cost (BDT/kWh) Flat rate for commercial and office consumers	9.12 (unit price)	9.12 (unit price)
5.	Total cost (BDT/year)	520×9.12 = 4,742.4 (Min) 830×9.12 = 7,569.6 (Max)	700×9.12 = 6,384 (Min) 1100×9.12 = 10,032 (Max)
6.	Benefits: energy and cost saving	180 - 270 kWh/year 1,641.6 – 2,462.4 BDT/year	---
		For Laboratory	
1.	Price (BDT)	350 (average unit price- only for light) 350×8 = 2,800	120 (average unit price- only for light) 120×8 = 960
2.	Average illuminance level (lx)	564	325
3.	Energy consumption (kWh/year)	350-550	350-550
4.	Energy cost (BDT/kWh) Flat rate for commercial and office consumers	9.12 (unit price)	9.12 (unit price)
5.	Total cost (BDT/year)	350×9.12 = 3,192 (Min) 550×9.12 = 5,016 (Max)	350×9.12 = 3,192 (Min) 550×9.12 = 5,016 (Max)
6.	Benefits: quality of light	Increased illuminance level (564 – 325 = 239 lx)	---

* Bangladeshi currency, 1 USD = 84 BDT

There is a total of 41 rooms on each floor (approximately 2,600 square meter) in the academic building (nine-storied) and they are located face-to-face, of which, 15 and 26 are classrooms and laboratories, and offices, respectively. Of the 15 classrooms and laboratories, eight are similar to the room shown in Fig. 1, and the other seven rooms are as depicted in Fig. 3. The academic building is west-facing and nine-storied, with an auditorium and a large exam hall on the ground and top floor, respectively. Although there are few classrooms and laboratories, in estimating the energy and cost-saving, the ground and top floors were excluded. There were eight rooms on each floor from which it is possible to save energy and cost through this LED lighting system. The total number of potential classrooms for this purpose would be 56 (8×7) and the total energy-saving per year would be between 10,080 kWh and 15,120 kWh. This type of LED lighting system could save from BDT 91,929.6 to BDT 137,894.4 per year.

With respect to GHG emission reduction due to this energy saving, it was estimated that 6,753 to 10,130 kgCO_2-eq could be saved per year by avoiding fossil-fueled electricity generation. For this estimation, the average yearly carbon intensity of 670 gCO_2-eq/kWh was considered for Bangladesh [12], [22].

4. Discussion

Personal communication with the non-academic and academic staff members of many different public universities in Bangladesh reveals that almost every university in the country uses typical fluorescent tube lights in their classrooms and offices. Clearly, the use of LED lights in these educational institutions is capable of saving electrical energy. The use of LED not only saves energy but also offers economic and environmental benefits. University students found that LED light is more attractive, efficient, stimulating, comfortable, and cutting-edge technology compared to fluorescent light [4]. After life expiration, normal fluorescent tubes could be harmful to the environment and human health as they contain phosphor and mercury. Due to the lack of proper waste management systems in least developed countries, expired fluorescent tube lights are a major threat to the environment, as outdated light manufacturing materials such as mercury could mix with soil and water. On the contrary, LED tubes do not have these chemicals. Ballast is also required for the operation of fluorescent tubes, which not only adds to the cost of the lamp but is also responsible for the typical buzzing noise. Often, fluorescent tube lights become dull and flicker frequently, whereas LED tube lights do not have these problems. Although LED offers many advantages over typical fluorescent tube lights, the cost of the former is about three times higher than the latter.

The overall efficiency of LED lighting systems depends on many parameters such as reflectance factors. We varied the reflectance factor of ceiling, walls, and floor with a MF of 80%, and the results are presented in Table 3. Notably, an effective optimization between the ceiling, walls, and floor color is required to gain maximum lux output from a lighting system in a room. For different colors, the reflectance factors are different. Although the reflectance factors for these three surfaces are recommended in the developed world [23] for efficient lighting system development, in the least developed and developing world they are rarely seen.

Table 3 Illuminance level variation due to different reflectance factors of the surfaces for the class- and laboratory room.

Sl. No.	Ceiling RF (%)	Walls RF (%)	Floor RF (%)	Classroom average (lx)	Laboratory average (lx)
1.	75	75	75	604	453
2.	75	75	50	564	437
3.	50	75	50	535	424
4.	50	75	16.3	503	405
5.	50	75	25	501	409
6.	50	50	50	491	399
7.	50	75	12.5	491	404
8.	25	75	50	489	402
9.	12.5	75	50	474	395
10.	50	50	16.3	470	389
11.	50	25	50	467	383

Although LED lighting systems offer several benefits over fluorescent tube lights in educational institutions, the implementation of this efficient design faces several barriers. First, the lack of information. The initial cost of LED is indeed higher than that of fluorescent tube lights, and the lifecycle saving from the LED lighting system is frequently not taken into account by the proper authority due to the absence of available information.

Second, the lack of environmental awareness. In developing and least developed countries, one of the primary uses of electricity is for lighting and consumers are not aware of electricity generation. The negative impact of fossil-fueled electricity generation and its consequences on the environment and human health thus receive less attention.

Third, rigidity to change. Often the government and the authorities emphasize procuring electricity from known suppliers at a cheap rate, but these suppliers are most often unable to supply energy-efficient goods due to a comparatively high initial price. Moreover, the staff involved in this procurement process is not well informed about the advantages of energy-efficient options.

Fourth, the lack of energy management (i.e., demand side management) strategies. In developed countries, most educational institutions, predominantly universities, have their own demand side management strategies to reduce energy consumption towards sustainable development. This type of strategy is completely absent in educational institutions, mainly due to the lack of research in this field in least developed countries [24].

Finally, the lack of technical expertise in lighting system design. During planning, construction, and the interior design of any building, most often priority is given to civil engineers and architects. Lighting system design is usually completed by the local electrical technician who has zero knowledge of lighting efficiency factors.

To overcome these barriers, policymaking needs to be revised or developed. Some recommendations for these changes include:

- Awareness and development of procurement staff through different training and programs, so that they can make optimal decisions regarding efficiency and costs while procuring new lighting systems. These awareness programs must include environmental and sustainable development issues.

- To obtain proper information regarding energy-efficient lighting and its benefits, consultation with experts in this field would be an effective approach. An energy audit by a professional could also be helpful for this.
- For educational institutional lighting system design, a lighting system expert or lighting engineer should be employed during the planning and construction phases of the building. This is crucial as there are many parameters that need to be considered for a lighting system design [25].
- Every educational institution should launch demand side management schemes for their institute for effective utilization of energy resources, including lighting systems.
- The government of the country should develop regulations regarding the use of more efficient lighting system design and usage at educational institutions.
- At the initial stage, each institution should run a pilot project for a more efficient lighting system design, and consider the project's outcome.

5. CONCLUSION

In this study, a simulation exercise and practical measurement of lighting levels inside an educational building located in Bangladesh with the aim of understanding how a careful design of the lighting system may help reduce electricity needs and guarantee visual comfort was carried out.

To overcome the deficiencies of the existing system, a LED-based efficient lighting system was proposed. The results show that 25% of energy and cost per year could be saved from this type of lighting system. Although the proposed LED-based lighting system has higher initial costs than the typical fluorescent tube system, it offers long-term economic and environmental benefits. The lifetime of an LED tube light is almost twice that of a typical fluorescent tube light. Furthermore, the former does not contain any hazardous metals such as mercury, whereas the latter does.

For energy efficient lighting system design, the quality of light is equally important as the quantity of light, that is, increasing the number of lights is not necessarily a better option. Maximizing the use of daylight in conjunction with artificial lighting is another potential alternative to reducing energy demand in buildings, which must be taken into account during any lighting system design for educational institutions.

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