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Optimizing Natural Lighting Analyses for Existing Buildings to Minimize Usage of Artificial Lighting and Green House Gas Effect

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Abstract

Securing energy demand on continuous bases is becoming a vital element to achieve sustainable development. One of which is maximizing the dependency upon natural lighting during daytime for existing buildings to minimize the reliance upon nonrenewable resources and hence the unfavorable effect of greenhouse gases. A current analysis situation was done for university buildings using Building Information Model (BIM) software-natural lighting analysis to find answers for the research questions under the policy oriented research. All lighting spaces in the buildings were investigated to facilitate reviewing the output results. The results and analyses showed that the dependency on natural lighting could be used to reduce the amount of energy used via artificial lighting during daytime by nearly one third the amounts consumed; hence would result in reducing the operating cost. Moreover, carbon dioxide emissions would also be reduced by about 30% and would consequently result in the better wellbeing of the occupants, provide better health, reduce absenteeism, ameliorate productivity, and raise financial savings.

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Keywords: BIM software; GHG; energy consumption; natural and artificial lighting; green building; operating cost.

1. Introduction

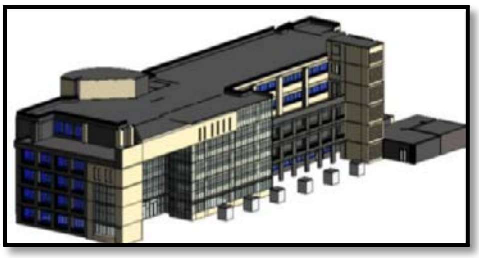
The potential of renewable energy sources such as biomass, wind, solar, hydropower, and geothermal is huge and could provide sustainable energy services and in theory meet the world's energy demand especially with the environmental hostile impact of fossil fuel emissions [8]. It is worth mentioning that these emissions are entrapped in the atmospheric layer increasing the overall temperature of the earth [3]. Hence renewable energy is the best choice for securing energy demand to the next generations with a cleaner environment. In Egypt, a strategy, which was approved in February 2008, aims to: "Contribution of renewable energies by 20% of the total electricity generation by the year 2020 [6].

Concerning educational buildings, their efficiency could be influenced by how the space is utilized. In order to maximize energy efficiency within a building, heat losses must be kept to a minimum by using insulation [7]. The implementation of solar energy solutions combined with energy efficient design can lessen the burden of the building on the energy sector [10]. A case study showed how a simple occupancy based lighting control system can save electrical energy and has a short payback period [2].

According to Sandanasamy [12], energy efficiency of buildings could be improved via a strategic use of natural light and hence eradicating carbon emission and global warming. Moreover, daylight harvesting assumes an area in a building, such as an office, will have a natural lighting source available during the daylight hours [4].Consequently, the application of innovative, advanced day-lighting policies and systems could significantly enhance the quality of light in an indoor environment. Long working hours exposed to artificial lighting (i.e lighting electricity) is believed to be harmful to human health whereas working in daylight is believed to result in less stress and discomfort. This is due to the fact that daylight provides the surrounding condition for good vision. Therefore, suitable, low cost, high performance daylight technologies are required to incorporate daylight planning during the building design phase and should come into action concerning existing buildings [12].

2. Methodology

The main focus of this research was to analyze the level of natural lighting inside existing university buildings during daytime. This was done using the natural lighting analysis [13] extinction on the Autodesk Revit [14] to minimize the dependence on artificial lighting in order to save energy, minimize the release of CO_2 which contributes to GHG effect and eventually decrease the operating cost. The study was applied on The Arab Academy for Science, Technology, and Maritime Transportation (AASTMT) which is an educational organization and a subsidiary of the Arab league. The buildings are located in the North-East of Cairo, Egypt. The university consists of three buildings. Building A (**Figure 1**) consists of a ground floor and four typical floors. Each of buildings B (**Figure 2**) and GS (**Figure 3**) consist of a basement, ground floor, and four typical floors. All buildings include administrational offices, lecture rooms, laboratories, cafeterias, and a library located in building A. Building Information Model (BIM) software-natural lighting analysis- was used to simulate the amount of natural lighting interring the buildings via generating a 3D model for the buildings and analyzing them. The reduction of artificial lighting usage is expected to reduce the amount of carbon dioxide (CO_2) gas produced by relating the electricity generated with greenhouse gases emissions, which would help in enhancing the surrounding environment and reduce the deprivation of non-renewable natural resources.



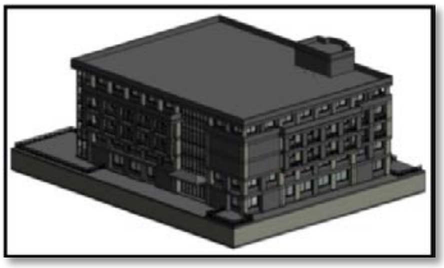


Figure 1: Building (A) **Figure 2:** Building (B) 3-D view **Figure 3:** Building (GS) 3-D view

3. Results and Analyses

This section shall display the results and analyses obtained from simulating the buildings to test the level of dependency upon natural lighting during the daylight time and the level of dependency upon artificial lighting. This shall then be followed by calculating the amount of CO_2 expected to be released before and after implementing green sustainable practices in addition to the approximate amounts of operating cost that could be saved.

3.1 Natural Lighting

From the analyses done using the above mentioned program, **Figures 4** to **15** and **Tables 1** to **3** display the natural lighting analysis results for the three buildings generated by the program. The shown colors refer to the percentage of natural lighting in the area according to the annexed light scale which can be used to determine the amount of artificial lighting needed and the reliance on the natural lighting.

- Building A:

Building A is the largest of the three buildings investigated in this research. **Figure 4** shows the area of the building mostly exposed to the sun which is the roof. Hence the light color illustrates maximum exposure to the sunlight. **Figure 6** presents the distribution of the sun rays penetrating the windows throughout the façade of the building from the four directions.

The intensity of the sunlight varies right from the surface at the windows till the inner midway of the corridor. The value of light intensity is presented in LUX as shown in **Figure 5** for the 4th floor**.** As generated from the simulation, the darker the color distribution is the weaker the effect of sunlight entering the rooms. The percentages and areas of lightness and darkness are presented in **Table 1**for each floor at 9am and 3pm.**Figure 7** presents a comparison for the lighting effect at the different timings (9am and 3 pm) between the floors.

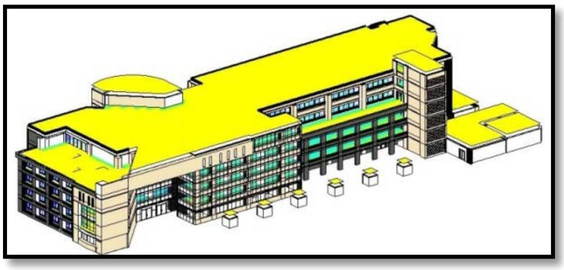


Figure 4: 3D lighting analyses for Building A.

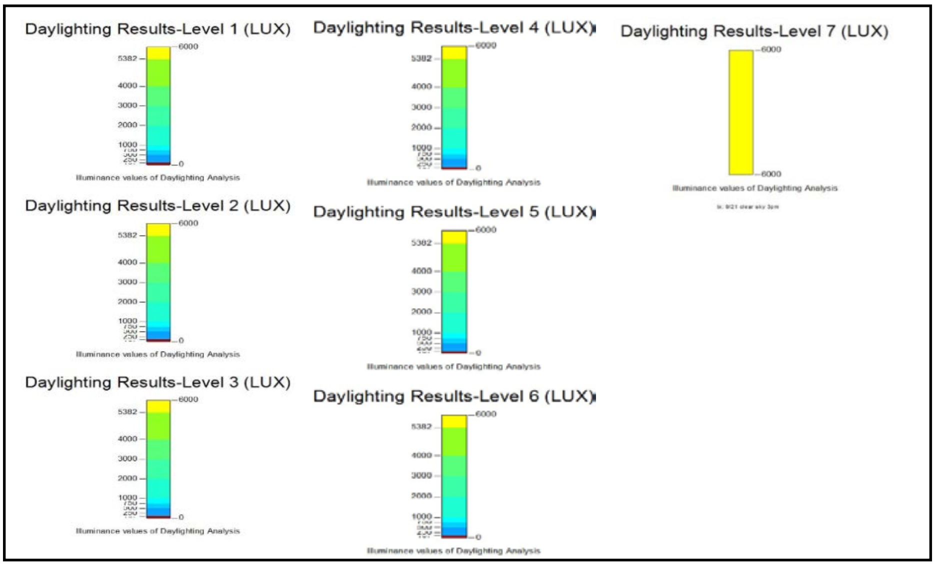


Figure 5: Light scale

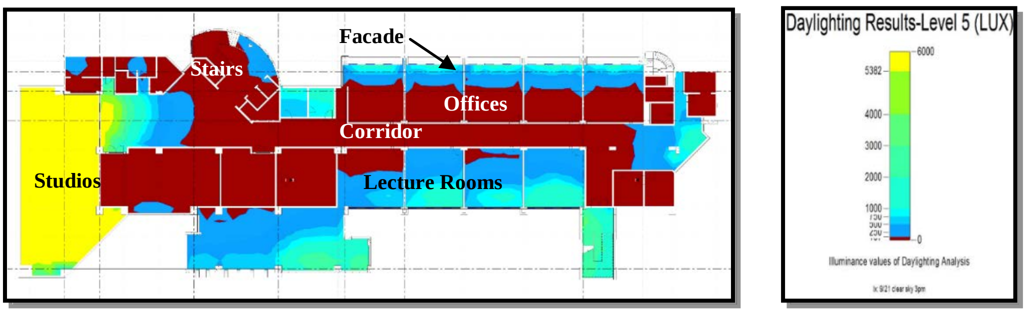


Figure 6: Building A: 4th floor

Table 1: Building A: Lighting Analyses Floor Schedule

Floor	Total area(m^2)	Daylight area(m^2)	Threshold results											
			9am						3pm					
			Brightened Zone		Darkened Zone		Intermediate Zone		Brightened Zone		Darkened Zone		Intermediate Zone	
			%	area	%	area	%	area	%	area	%	area	%	area
Ground	2527	2352	70	1646	0	0	30	706	70	1646	0	0	30	706
First	2136	2075	36	754	1	14	63	1307	36	748	2	37	62	1290
Second	2134	2039	36	731	0	7	64	1301	37	754	1	30	62	1255
Third	2019	2019	39	796	0	7	60	1216	41	820	2	33	58	1166
Fourth	2158	2158	38	827	12	259	50	1072	37	797	13	283	50	1078
Roof	105	105	0	0	0	0	100	105	0	0	0	0	100	105

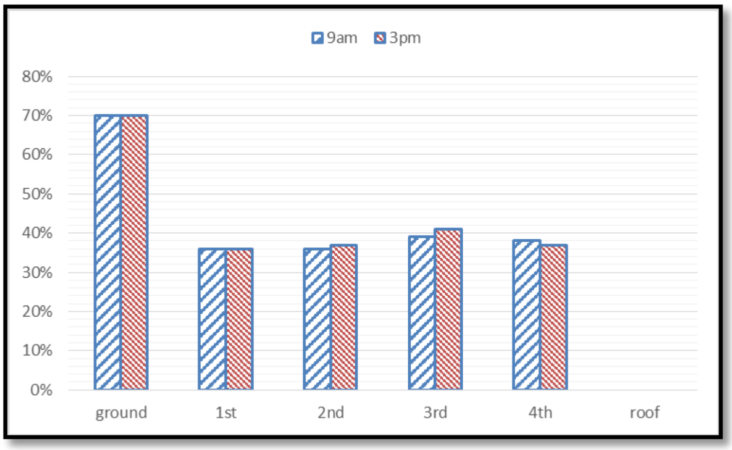


Figure 7: Percentage of light distribution for each floor

- Building B:

Building B was the second building simulated for natural day lighting. **Figure 8** shows the orientation of the building and how its shape has affected the area that could have allowed more sunlight radiance if it was similar building A. Moreover the building has protrusions above the windows and according to Marks and Wood well [11], this would limit the angle of light passing through the windows; hence would affect the degree of illumination inside the classes. **Figure 10** presents the distribution of the sun rays penetrating the windows throughout the inner (limited sunlight penetration) and outer façade of the building where the lecture rooms are nearly naturally fully illuminated. The value of light intensity is presented in LUX as shown in **Figure 9**for the 1st floor**.** As generated from the simulation, the darker the color distribution is the weaker the effect of sunlight entering the rooms. The percentages and areas of lightness and darkness are presented in **Table 2**for each floor at 9am and 3pm. **Figure 11** presents a comparison for the lighting effect at the different timings (9am and 3 pm) between the floors.

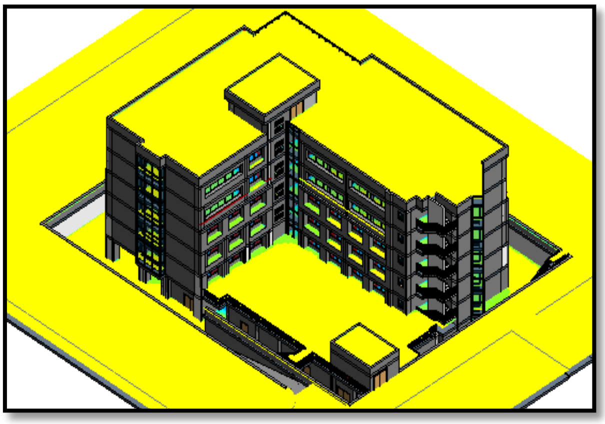


Figure 8: Building B: 3D lighting analyses.

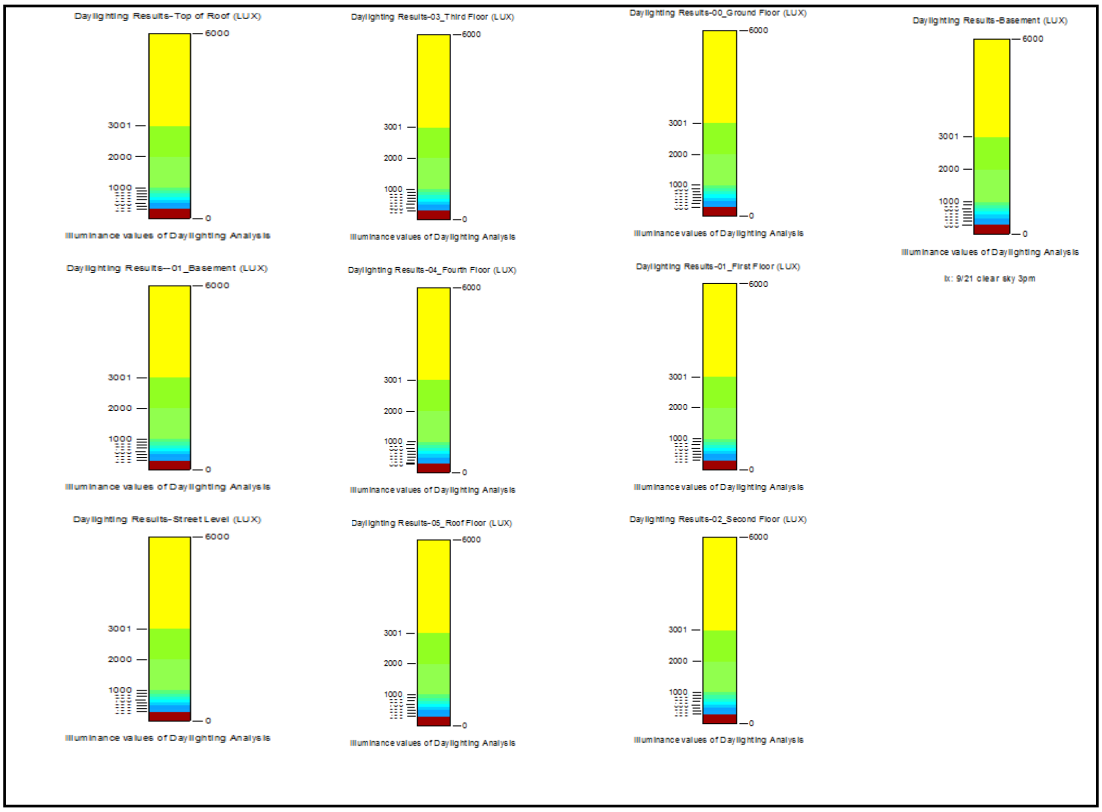


Figure 9: Natural Lighting scale analysis.

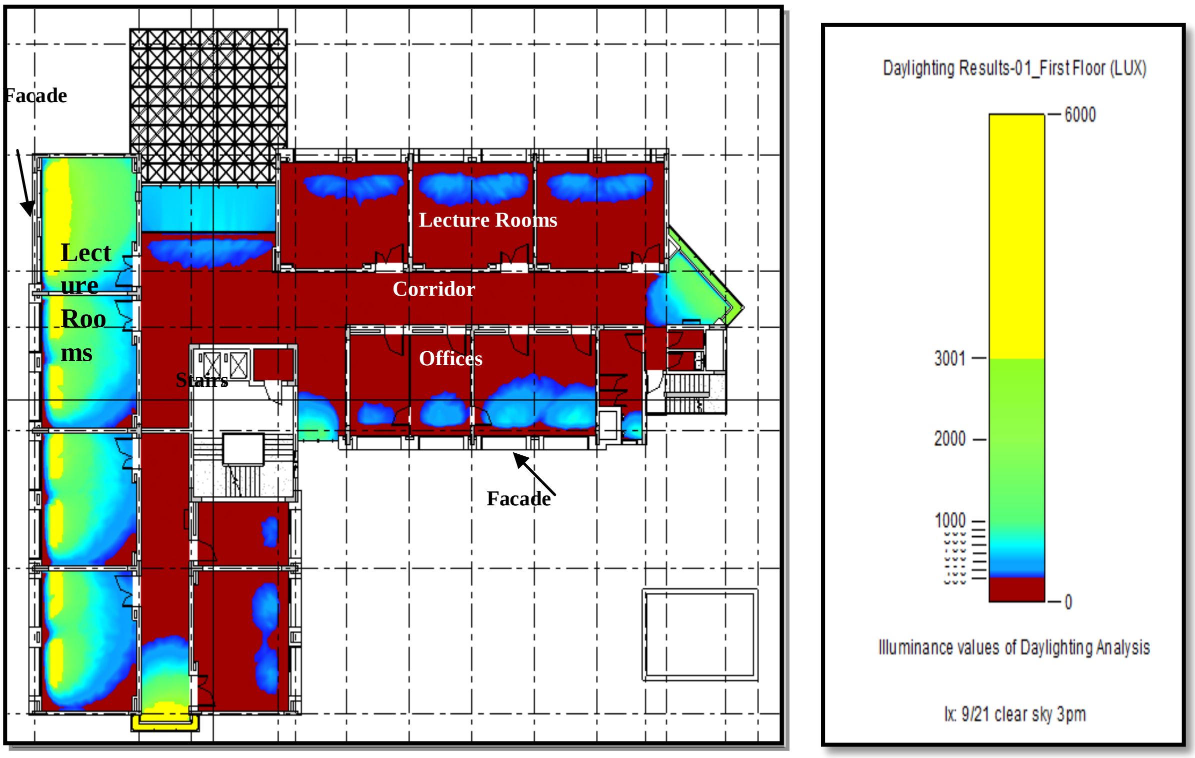


Figure 10: Building B: 1st floor

Table 2 : Building B Lighting Analyses Floor Schedule.

Floor	Total area(m^2)	Daylight area(m^2)	Threshold results 9am Brightened Zone %	area	Darkened Zone %	area	Intermediate Zone %	area	3pm Brightened Zone %	area	Darkened Zone %	area	Intermediate Zone %	area
Basement	694	694	0	0	0	0	100	694	0	0	0	0	100	694
Ground	651	651	32	206	3	17	66	428	34	220	3	19	63	413
First	632	632	28	178	2	14	70	440	35	218	3	19	62	394
Second	627	627	32	201	2	13	66	412	40	249	3	19	57	359
Third	631	631	43	274	3	21	53	336	47	294	6	35	48	302
Fourth	616	616	47	288	4	23	50	305	47	288	7	40	47	287
Roof	43	43	0	0	0	0	100	43	0	0	0	0	100	43

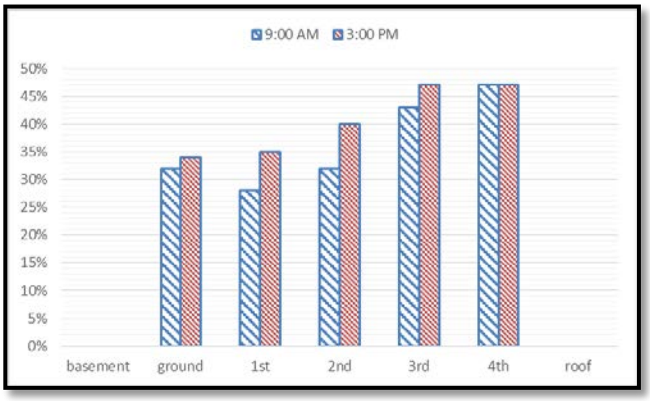


Figure 11: percentage of light distribution, floor analyses**.**

- Building Graduate studies (GS):

Building GS was the third and last building simulated here in. **Figure 12** shows the orientation of the building which is similar building A, but smaller in size. **Figure 14** presents the distribution of the sun rays penetrating the windows.The rooms are nearly naturally fully illuminated. The lecture rooms have smaller areas; consequently the sizes of the windows are sufficient and allow high levels of sunlight to illuminate the rooms opposed to Building A. The value of light intensity is presented in LUX as shown in **Figure 14**for the ground floor**.** As generated from the simulation,the darker the color distribution is the weaker the effect of sunlight which is mainly localized in the core of the building. The percentages and areas of lightness and darkness are presented in **Table 3**for each floor at 9am and 3pm. **Figure 13** presents a comparison for the lighting effect at the different timings (9am and 3 pm) between the floors.

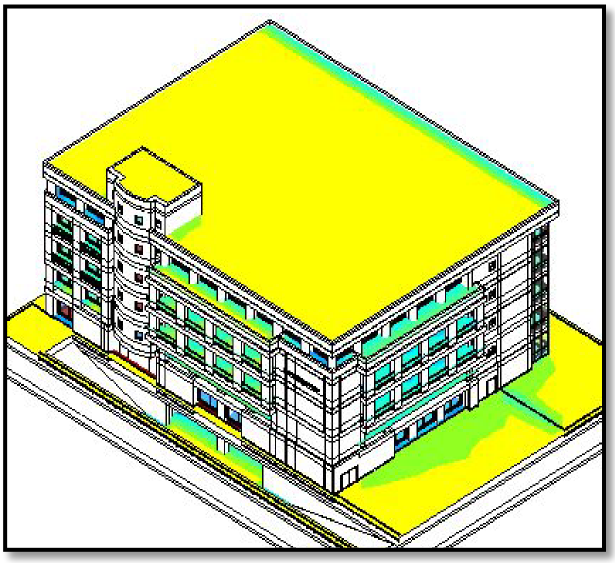


Figure 12: 3D lighting analyses for Building GS.

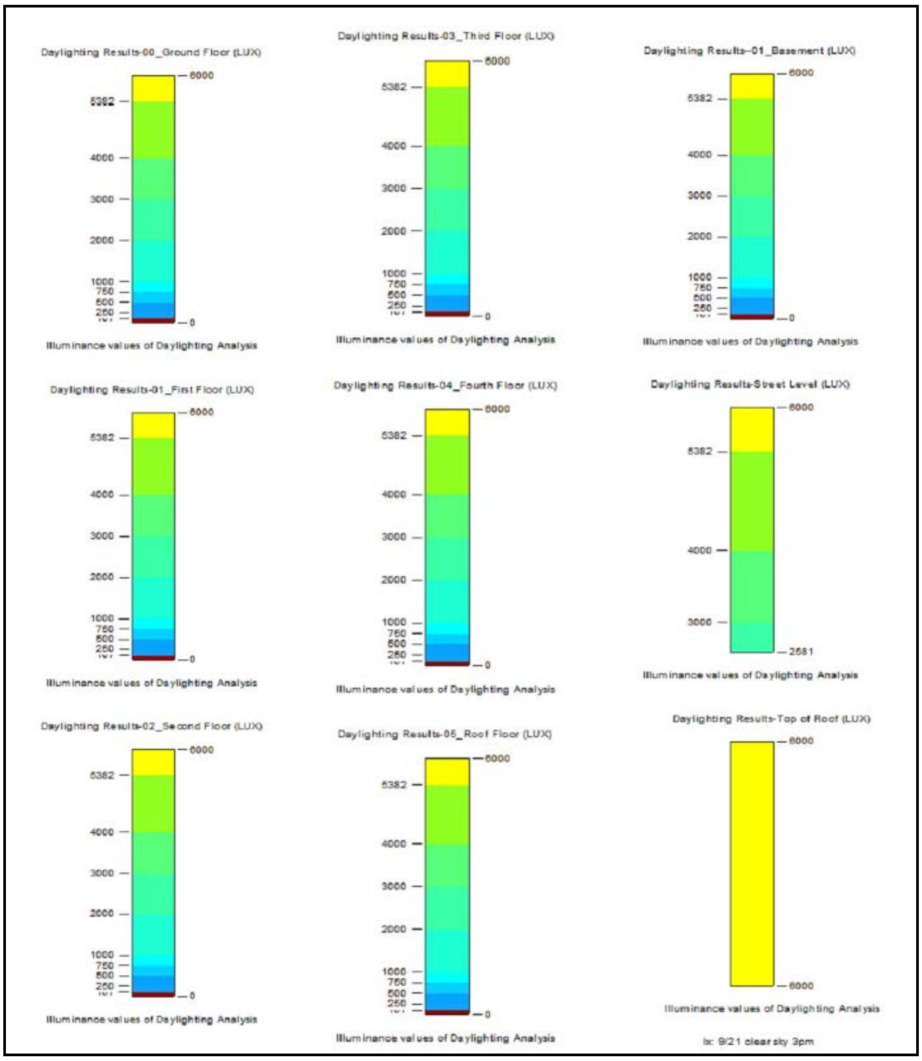


Figure 13: Natural lighting scale analysis.

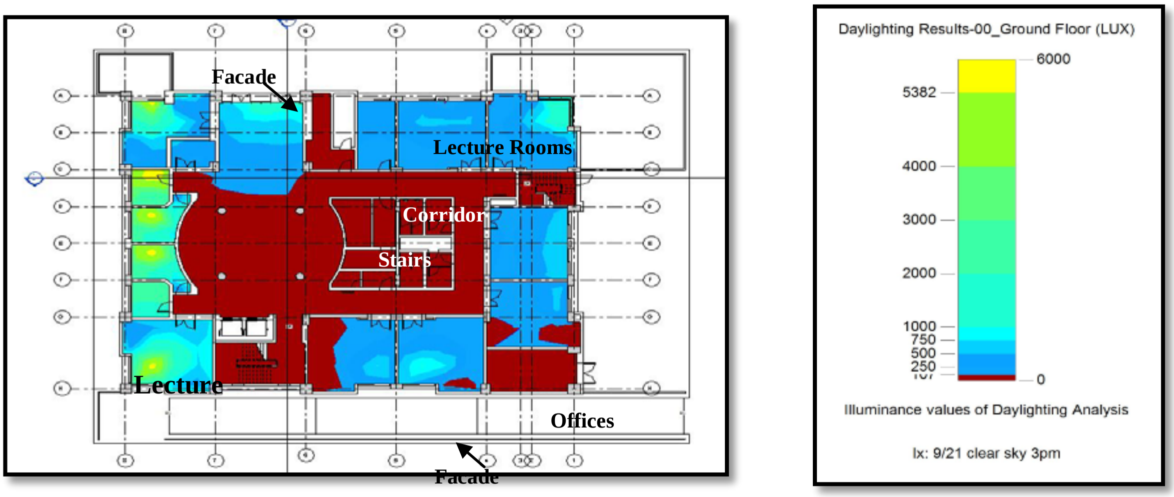


Figure 14: Building GS: ground floor.

Table (3): Building GS Lighting Analyses Floor Schedule.

Floor	Total area(m^2)	Daylight area(m^2)	Threshold results											
			9am						3pm					
			Within		Above		Below		Within		Above		Below	
			%	area	%	area	%	area	%	area	%	area	%	area
Basement	1670	1670	9	149	4	59	88	1462	9	142	4	59	88	1469
Ground	936	912	49	449	2	14	49	448	47	427	2	18	51	466
First	904	900	53	479	0	0	47	420	55	492	0	0	45	407
Second	911	881	41	363	0	4	58	514	41	357	1	8	59	516
Third	911	881	41	365	0	4	58	512	40	356	1	8	59	518
Fourth	881	851	55	466	0	4	45	328	57	483	0	0	43	368
Roof	29	29	0	0	0	0	100	29	0	0	0	0	100	29

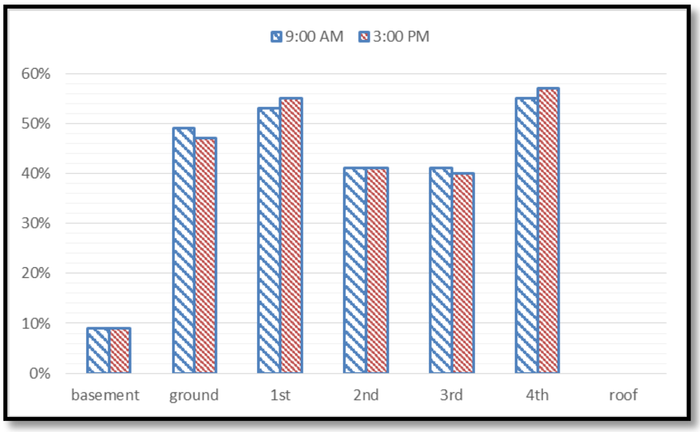


Figure 15: percentage of light distribution, floor analyses**.**

3.2Artificial Lighting

From the above results and analyses, if sustainability practices are applied via the use of high efficiency electronic ballastsand depending on natural lighting during days times as illustrated above, it would be possible to decrease the amount of energy consumed as computed and presented in **Table 4** and **Figure 16**. This is based on computing the number of hours in which there shall be full dependence upon natural lighting (from 6 am till 3 pm) and the remaining working hours which would range from 3 pm till 9 pm. This is expected to decrease the amount of energy consumed by nearly 30 %. It is worth mentioning that lighting in typical buildings could account for 25-40% of the total amount of energy consumed [16].

Table 4: Total energy consumption before and after the application of sustainable practices.

Building	Consumption (kw/year) before the application of sustainability practices	Consumption (kw/year) after the application of sustainability practices
A	1353325.2	902462.016
B	1160835.0	895381.368
GS	1260656.4	883161.912
Total	**3774816.6**	**2681005.296**

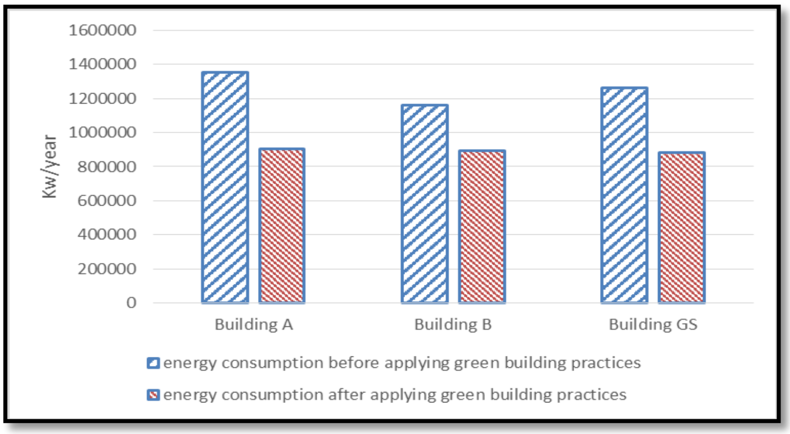


Figure 16: Total energy consumption beforeand after applying green building technologies.

3.3 Greenhouse gas emissions

Greenhouse gas emissions could be considered one of the most threatening causes on climate change, one of these emissions is CO_2 gas where major efforts are maintained to decrease its concentrations [9]. In this study and based on the former result the reduction of artificial lights would result on reducing the greenhouse gas emission as shown in **Table 5** and illustrated in **Figure 17.**The amount of gas expressed by CO_2 and the electricity generated by the formula **1kw =1.68 lb CO_2** of (Distillate Oil) was used to compute the expected amount of CO_2 to be emitted.

Table 5: Amount of CO_2 produced before and after the application of sustainability practices. **Source:** [1].

Building	Amount of CO_2 produced (lb/year) Before applying sustainable practices	Amount of CO_2 produced (lb/year) After applying sustainable practices	Percentage Reduction
A	2273586.336	1516136.187	33.31%
B	1950202.8	1504241	22.86%
GS	2117902.75	1483712.01	29.94%
Total	**6341691.88**	**4504088.897**	28.97%

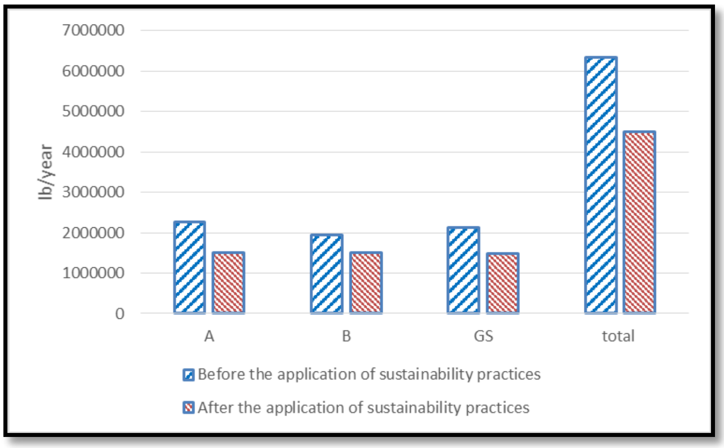


Figure 17: Amount of CO_2 produced before and after the application of sustainability practices.

4. Conclusion

BIM software -natural lighting analysis was used in this study to simulate the level of natural lightening entering the three buildings of the university. The simulation clarified the mechanism of determining the natural lighting percentages in the buildings for each floor. Using this feature, buildings A, B, and GS were analyzed giving highly accurate results in order to determine the additional amount of artificial lighting needed.

In brief, the following could be concluded from this study:

- The amount of energy consumed could be reduced by about 29 % on average for the three buildings.
- This would result in reducing the greenhouse gas emissions, mainly CO_2 gas by 28.97 %.
- The operating cost is also expected to be reduced by nearly 30%.
- As stated by Edwards and Torcellini [5], the dependence on daylight is expected to result in s better wellbeing of the occupants, provide better health, reduce absenteeism, ameliorate productivity, and increase financial savings.

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