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An Analysis of the Lighting and Energy Saving Capabilities of Tubular Daylighting Devices (TDDs)

"A Case Study of a Laboratory in Cairo, Egypt"

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Abstract

All types of buildings require lighting and consume a lot of electricity. Tubular daylighting devices (TDD) can be an alternative, A sun tunnel is an innovative yet cost-effective way of allowing and promoting natural light. Designed especially for those areas of the house that can't reap the benefits of natural sunlight, (TDD's) also influences the thermal comfort in the spaces, as it limits the heat gain in the spaces that feed them with natural light. This research provides a method to enhance Energy Use Intensity (EUI) in a laboratory room through minimizing artificial light usage and thermal heat gain Accompanied by natural light minimizing energy use by 18% could be beneficial at laboratories in universities building as they are one of the main energy consumers between other spaces enhancing thermal performance of indoor spaces as well. This study indicates the significant potential for energy savings and daylighting advantages of employing the planned lighting-heating coupled TDDs system in buildings.

Keywords: Tubular Day Light Devices (TDDs), Energy Efficiency, Educational Spaces, Laboratories, Spatial day lighting Autonomy (SDA).

1. INTROUCTION

The consumption of energy in buildings sector has been significantly rising, around 40% of the total energy consumption worldwide. also 38% of carbon emissions is through building sector. daylighting is one of the natural solutions to replace energy consumed through artificial lighting.

Traditional Artificial lighting such as light emitting diode (LED) has luminous efficiency of around 100-120 LmlW . LED is powered by electricity that converts 40-60% of electric power to heat gain, which increase cooling loads through the total energy consumption. despite the importance of daylighting, it cannot reach through many res in the building such as basements and spaces that don't have outer overlook.

Daylighting devices have been witnessing a lot of development through the last decade, which can guide light by continuous reflections specially in underground or enclosed spaces.
In addition, tubular Daylight Devices (TDDs) can reduce the solar gain and achieve adequate daylight levels in addition to bring usable daylight into the interior of buildings or into spaces that aren't naturally illuminated.
In Areas close to building openings, conventional window systems can give enough light (the perimeter). If you want to enlarge this area, you can either use a design plan that takes into consideration a new building form.

2. Daylight Metrics

This study is aims at comparing daylighting simulation measures of computer lab before and after conducting tubular Daylight Devices (TDDs) By measuring the indoor lux values. Daylighting level must be adequate to be 500 lux for the design to replace the LED lights used in the space. For this study, Climatestudio analysis program was used. The temperature and environmental data for a place in 6TH of October city are used in this study. The window-wall ratio, façade orientation, construction of wall material and R-Value of opaque materials are examples of building characteristics that used in this model. The objective Daylight Factor must be used to compare energy performance (DF).[1]

2.1 Daylight Factor

Daylight factor (DF) is defined as the ratio between the illuminance at a point in a building divided by the illuminance at an upward facing, unshaded outside sensor [2] Daylight factor serves as a daylight availability metric in multiple building standards world-wide, with minimum requirements typically ranging between 2% and 5%.

2.2 Spatial Daylight Autonomy (sDA)

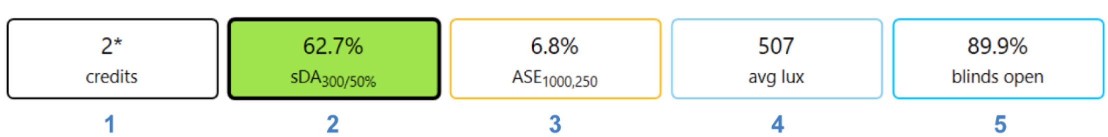
The first metric is Spatial Daylight Autonomy (sDA), a measure of daylight illuminance sufficiency for a given area, that represents a percentage of floor area that exceeds a specified illuminance level (e.g. 300 lux) for a specified amount of annual hours (e.g. 50% of the hours from 8am-6pm). The sDA value between 55% and 75% indicates a space in which daylighting is "nominally accepted" by occupants specially in computer lab Spaces.

2.3 Annual Sunlight Exposure (ASE)

Annual Sunlight Exposure (ASE), The percentage of the regularly occupied floor area that is "overlit." In this context, "overlit" locations are those receiving direct sunlight (>1000 lux directly from the solar disc) for more than 250 occupied hours. which provides a second dimension of daylight analysis, looking at one potential source of visual discomfort direct sunlight. Both metrics use the same building information and simulation methodology to analyze hourly illumination patterns, summed for an annual period

2.4 LEED v4 Daylight Option 1

Leadership in Energy and Environmental Design (LEED) is a green building rating system maintained by the US Green Building Council (USGBC). The system offers two simulation-based options for achieving its Daylight Credit, the results panel will show a dashboard with five key metrics:



Credits: The number of points the building qualifies for. Points are based on the total spatial daylight autonomy (sDA) of all qualifying areas. Areas that receive too much direct sunlight (ASE) are automatically disqualified from the total under LEED version 4.0, though not under version 4.1.

2.5 Mean Illuminance

The average illuminance over the regularly occupied floor area over all occupied hours.

Type of interior, task or activity

Educational premises		$\bar{E}_m$	UGR_L	U_o	R_a
Nursery school, play school	Play rooms	300	22	0.4	80
	Nurseries	300	22	0.4	80
	Handicraft rooms	300	19	0.6	80
Educational buildings	Classrooms, tutorial rooms	300	19	0.6	80
	Classrooms for evening classes and adults education	500	19	0.6	80
	Lecture halls	500	19	0.6	80
	Black, green wallboards and whiteboards	500	19	0.7	80
	Demonstration tables	500	19	0.7	80
	Art rooms	500	19	0.6	80
	Art rooms in art schools	750	19	0.7	90
	Technical drawing rooms	750	16	0.7	80
	Practical rooms and laboratories	500	19	0.6	80
	Handicraft rooms	500	19	0.6	80
	Teaching workshops	500	19	0.6	80
	Music practice rooms	300	19	0.6	80
	Computer practice rooms (menu driven)	300	19	0.6	80
	Language laboratories	300	19	0.6	80
	Preparation rooms and workshops	500	22	0.6	80
	Entrance halls	200	22	0.4	80
	Circulation areas, corridors	100	25	0.4	80
	Stairs	150	25	0.4	80
	Student common rooms and assembly halls	200	22	0.4	80
	Teachers rooms	300	19	0.6	80
	Library: bookshelves	200	19	0.6	80
	Library: reading areas	500	19	0.6	80
	Stock rooms for teaching materials	100	25	0.4	80
	Sports halls, gymnasiums, swimming pools (general use)	300	22	0.6	80
	School canteens	200	22	0.4	80
	Kitchens	500	22	0.6	80

Figure 1:The illuminance needed in educational building spaces
Source: https://www.zumtobel.com/PDB/teaser/EN/lichthandbuch.pdf
Accessed: 2022-12-23

3. Objectives:

This paper aims at enhancing daylighting performance in a closed laboratory In case of an existing educational building located in Cairo, Egypt. By examining the effect of adding Tubular daylighting devices (TDDs) to provide total daylighting without the need to artificial lighting and its impact in energy efficiency.

4. Research Problem:

According to the illuminating Engineering society of North America (IESNA) and European Standards (CEN) , the amount of daylighting needed for Educational Spaces where demonstrated , as they affect the users' performance significantly especially in deep plans that has no access to the daylight .

5. Research Methodology:

Using (TDDs) We managed to have the useful daylight reaching the laboratory space which enhanced the performance of Daylighting illumination, a computer simulation was conducted by the researchers using Climate studio for Rhino, to model the space base case simulating the results of (EUI), (SDA), in the case of using artificial lighting comparing it with the case of using (TDDs)[3]

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6.The Selected Case Study

The selected case study is a computer lab space in a university building with area 30.24 m^2 the dimension of the lab. As represented in figure (4) the height is 3m, the lab is completely isolated from the building perimeter with no external windows as shown in figure (2,3), the only windows exist is overhead windows overlooking the service corridor.

Figure 3:The reflected daylight in the lab from the acrylic vault above surrounding lab corridor

Figure 2: Artificial lighting in computer lab

Figure 5: acrylic vault above corridor

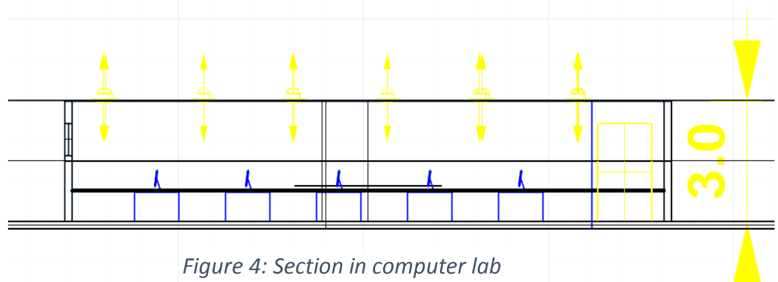

Figure 4: Section in computer lab

Source: **Researchers**

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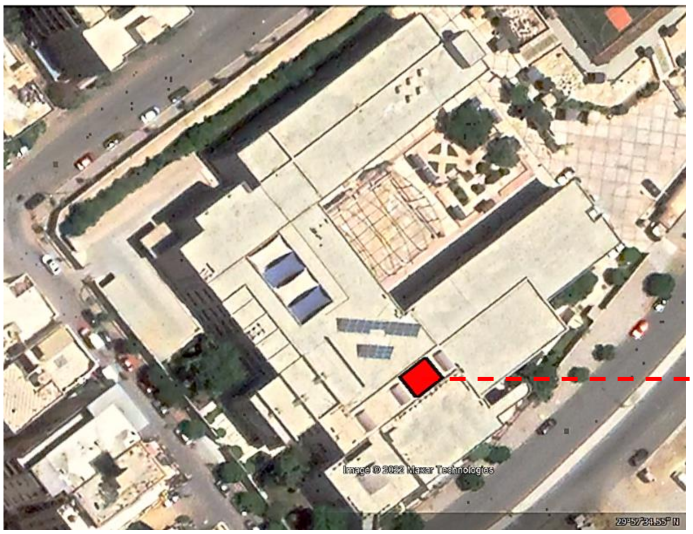
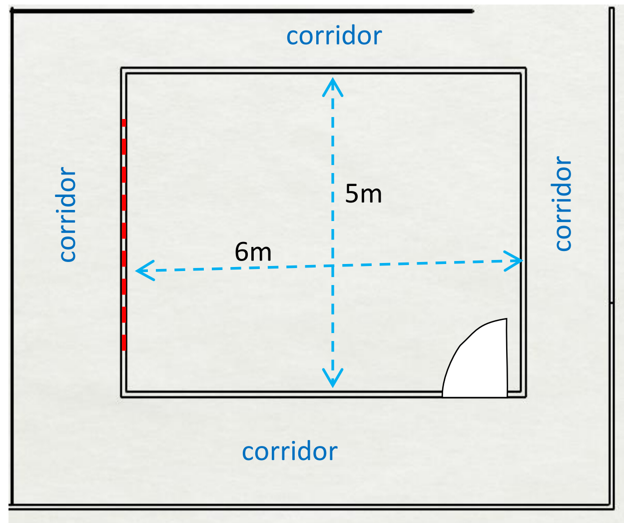
7. Explanation and analysis of the simulation study

The occupancy schedule is from 8am to 4pm the working plan is above 75 cm above the floor level.

The sensors grid plan is every 40cm and 50cm against the wall the number of sensors is 352.





8. Case Study Results

By simulating the computer lab space base case model, the (EUI) were measured to be 173 KWh/m^2 and the sDA result is 0% figure (7) the avg Lux is 100 while the ASE is 0% , **after** conducting (TDDs) the (EUI) were measured to be **120** Kwh/m^2 and the **sDA** is 71% and avg Lux is **370** also ASE is 0% Due To nonexistence of overlit areas figure (6), while through the energy use breakdown we managed to eliminate the artificial lighting loads from the annual energy consumption. Figure (11,1

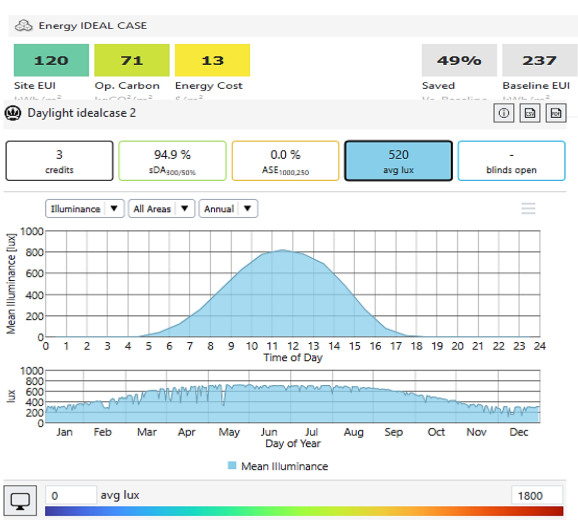


*Figure 7: The (EUI) and sDA By using **TDDs***

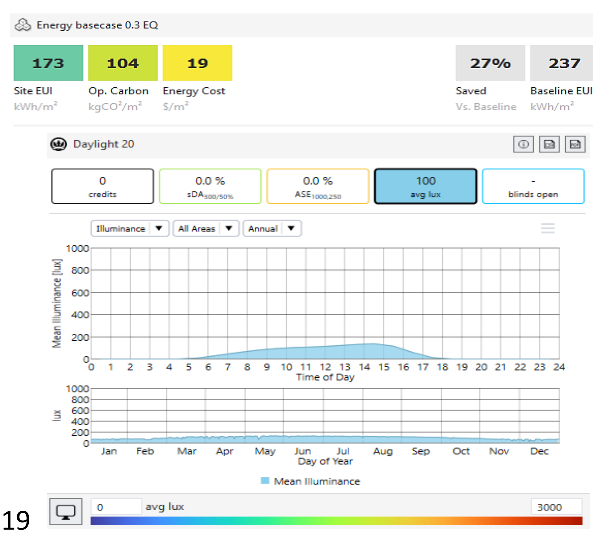


Figure 6: The (EUI) and sDA were measured for base case model

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9. Tubular Daylighting Devices "SolaTube"

Solatube Daylighting Systems are a new way of harnessing daylight. The tubular daylighting device which uses a reflective material was once fully utilized by the ancient Egyptians [4]. At present, this method has attracted extensive attention all over the world. Tubular daylight fixtures collect enough sunlight to illuminate without electricity. It is a good choice for some places without windows to transmit sunlight. Today, tubular daylighting devices are widely used, such as: Rooms without windows, tunnels, underground parking, corridors, etc.

Tubular daylighting devices consist of light collectors, light guides, and diffusers [5]. The principle of the tubular daylight device is that the light collector collects a large amount of natural light, and the light passes through the light guide plate and is reflected multiple times in the light guide plate to change the propagation direction of sunlight [6]. The light hits the diffuser below, bringing even light into the room. figure (8,10)

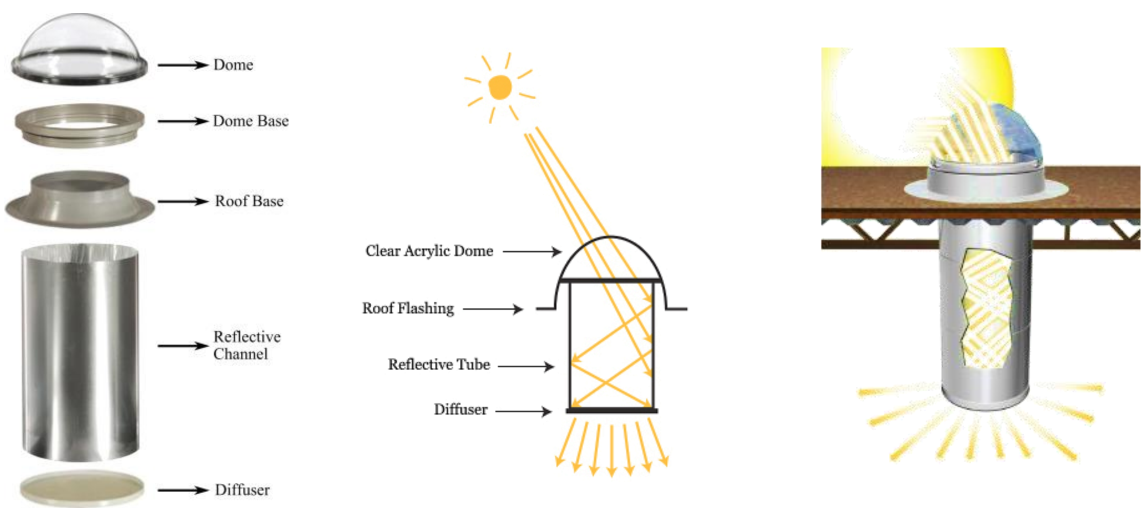

Figure 8: Tubular daylighting device component

10. SolaTube type selection

Solatube Daylighting Systems are engineered to efficiently capture the sun's rays and pipe them into the space. The result is brighter, more colorful spaces that cost nothing to light. And because installation can usually be done in about two hours with no structural changes, it's the fastest and simplest solution to a more beautiful home. figure (9)

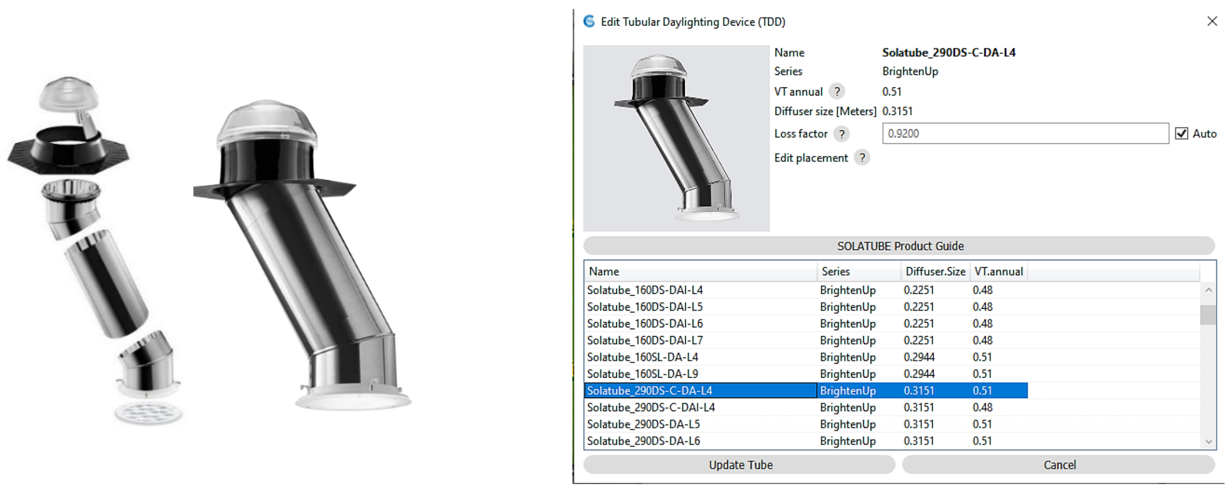

Figure 10: Selected SolaTube type at the Climatestudio simulation software

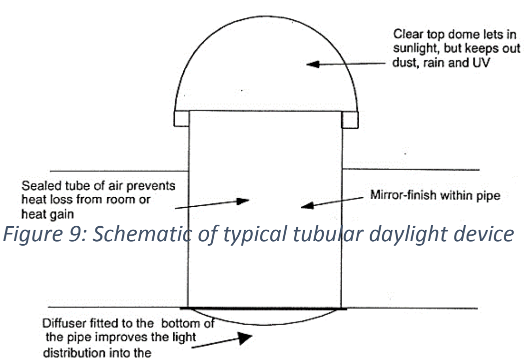

Figure 9: Schematic of typical tubular daylight device

Source: Illuminating Engineering Society (IES); The Daylight Metrics Committee, (2012). "Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE) [10]

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Based on the target room area (30 m²), the diameter of the TDD (**SolaTube**) was determined to be 315 mm based on Ref. [7] and the TDD product parameters, which give the recommended diameter for a given illuminated area by using **26** pieces of it to achieve the recommended lighting.

• Tube Size ≈ 14 in. (350 mm)
• Light Coverage Area ≈ 250-300 sq. ft. (23 - 28 sq. m)
• Potential Tube Length ≈ 30 ft. (9 m

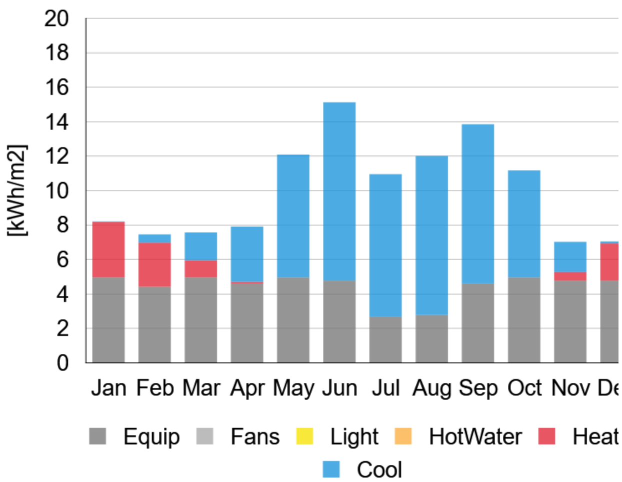

Figure 12: Energy Use Intensity (EUI) for ideal case by using SolaTube

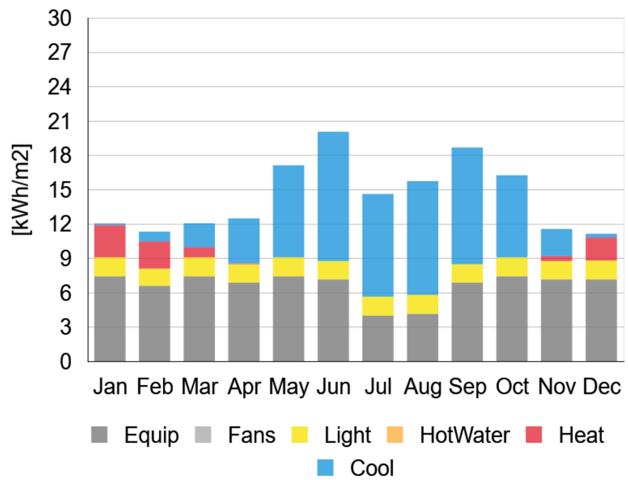

Figure 11: Energy Use Intensity (EUI) for base case by using artificial lighting

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11. Results of the simulation study

Table 1: Comparison simulation between base case and the model after adding TDD (SolaTube)

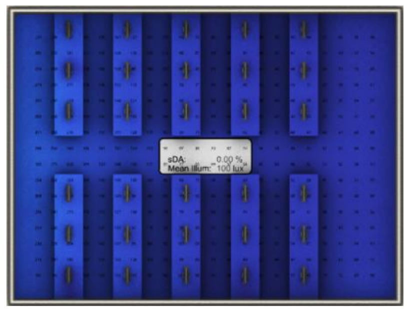
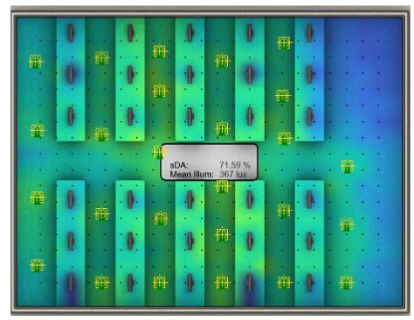
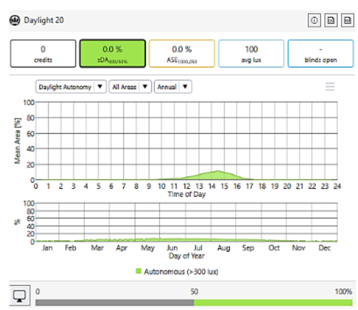
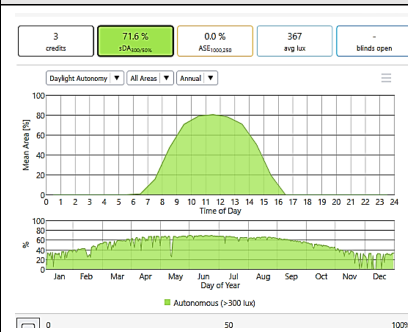
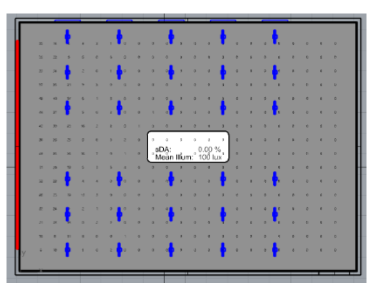
The result	Base Case	TDDS
1. Spatial daylight autonomy (sDA) and annual sunlight Exposure (ASE): The (sDA) has completely changed from 0% to 71% regular normal distribution of natural light. (ASE) is still 0% Due non overlit areas.		
The result	**Base Case**	**TDDS**
2. The LEED points After applying the (TDDs) the space managed to achieve 3 points of daylighting certification .		
3. lamp ,TDDs arrangement & sDA contouring **26 TDDs fixure were conducted to the space And shows normal distribution of illuminance mean illuminance of 370 lux wich is preferable range for laboratory spaces as (350-500)**		

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Figure 14: Rendered shot of the lab. After applying TDDs

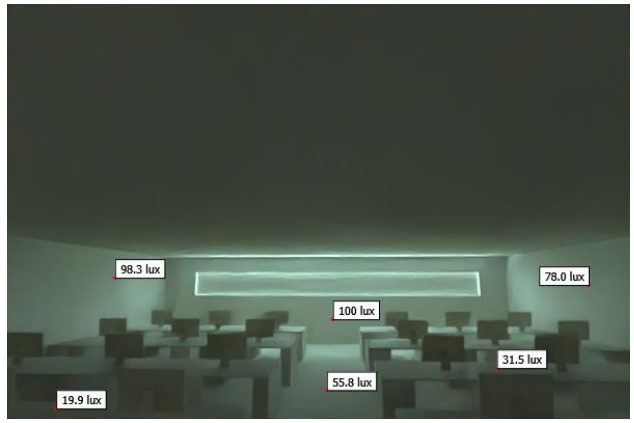

Figure 13: Simulation the computer lab for the base case show Lux Results

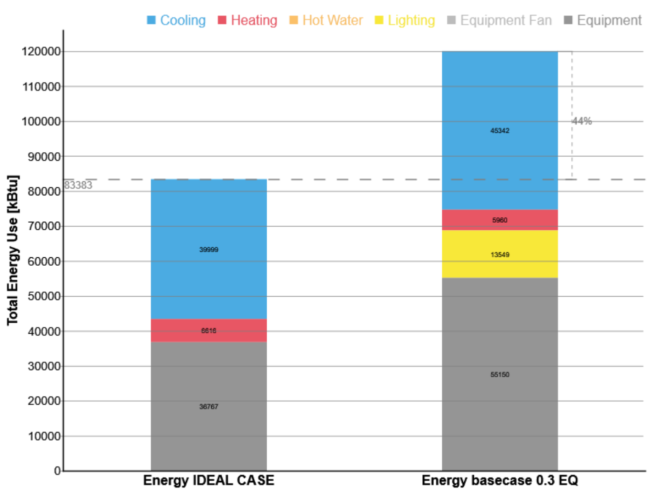

Figure 16: (Total energy use kw/h) Comparison chart for IDEAL case and base case

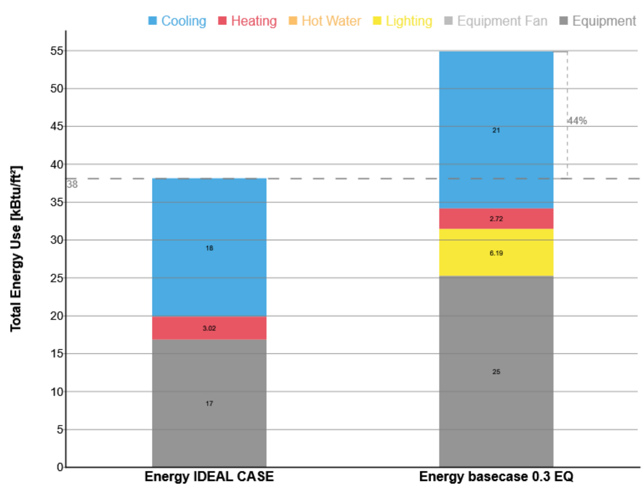

Figure 15: (Total energy use intensity kwh/m²) Comparison chart for IDEAL case and base case

Figure 17: LEED daylight report generated from simulation tool (Climatestudio) for ideal case

Software: ClimateStudio v1.9.8306.17105
Engine: Radiance 5.3
Weather: EGY_QH_Cairo.West.AP.623680_TMYx.epw
North Offset: 0°
Ambient Bounces: 6
Passes Completed: 100
Primary Ambient Samples: 6400

Objects	Material	Rvis	Tvis
CEILING	White Ceiling Panels	84.5%	0.0 %
FLOOR	Interior Flooring	37.7%	0.0 %
GLAZING	Azaria	11.2%	40.9 %
PARTITION	Off-white Plaster	83.7%	0.0 %
FURNITURE	Bookshelf	50.9%	0.0 %

Occupancy Space ID Occupancy Schedule 3 8am-6pm with DST

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12. Conclusion

We concluded that the solar tube's (TDDs) use produced SDA, EUI and avg Lux levels that were acceptable. And the number of solar tubes employed is carefully and experimentally chosen to avoid dramatically increasing the amount of light, which would raise the intensity of glare and have a negative impact on the users. also, the energy use breakdown managed to eliminate the artificial lighting loads from the annual energy consumption, besides being a source of natural daylight, it provides a form of 'healthy' daylight to students in a computer lab space.

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