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The effect of innovative daylight devices in raising the environmental efficiency and saving energy at library buildings

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Abstract:

This research introduces contemporary approaches to reintroduce natural lighting into established library building through the implementation of advanced daylight strategies, aiming to optimize the visual comfort essential for students. Utilizing cutting-edge technologies, particularly solar tubes, the study explores their application to enhance both visual and thermal comfort within existing library environments. The focus is on an autonomous structure within a university library at one of the engineering faculties in October City, employing simulation tools to forecast the efficacy of the proposed solution. The investigation delves into the impact of solar tubes on augmenting natural light penetration in dimly lit areas, emphasizing the potential advantages of revitalizing the natural lighting infrastructure in library spaces. Findings indicate a substantial enhancement in the natural lighting performance of library buildings through solar piping, leading to improved functionality for students and visitors, along with a notable reduction in energy consumption.

Keywords: *advanced daylighting systems; ClimateStudio; solar pipes; university libraries, environmental efficiency, energy consumption.*

1. Introduction

Natural light is an important source to achieve the level of lighting intensity as well as it is a good way to reduce energy use and is unlikely to be implemented in the near future as natural lighting has a distinctive characteristic that it has the ability to illuminate the built area and make it more interesting so the provision of natural lighting and control has taken great attention by architects and researchers interested in finding the optimal design to introduce natural building to provide energy during the day time and distribute it in a way that provides comfort to its occupants [1]. And that each space has rules for illumination, achieving physiological and psychological comfort, which is commensurate with the function of this space [2] Therefore, many applications have emerged to use natural light and transfer it to internal spaces without transferring heat with it, and among these applications are solar tubes where they take direct light from the sun and diffuse it to achieve a good distribution of daylight in the space [3].

2. Literature review

Research and scientific papers related to the subject of the study were reviewed and benefited from, and the following is a review of the most important studies related to the subject of the research.

Babarinde stated in "Achieving Visual Comfort through Daylight Devices (SolaTube) for Residential Buildings in Nigeria" [4] that the use of tube lighting devices is able to achieve visual comfort inside the spaces, as these tubes consist of three parts and consist in the opening at the top of the building (dome), which works to enter sunlight and contains a long tube that helps in Transfer light rays to diffusers, including the indoor unit, which contributes to reducing the temperature and glare, which leads to harm to users, as natural lighting is cheaper compared to traditional lighting. With different movement, which affects the performance of light tubes positively or negatively.

Ji et al.[5] by applying the tubular daylight device through the lighting design for the underground parking lot at Dalian University, which he carried out to achieve an energy-saving and comfortable lighting environment, through hybrid lighting systems and clarifying its components (optical lighting system and artificial lighting sources) where it leads to directing daylight in the optical lighting system with the integration of LED devices As a source of artificial light in order to make full use of daylight to reach an environment with energy-saving lighting and reach that the correct integration of hybrid lighting systems with daylight and LED lamps meets the lighting standards to be achieved and saves energy used in underground parking.

Mention Marouf and Abd El-Mawgood in [6] "Retrofitting Daylight in Educational Places Using Solar Tube" on the analysis of the role of solar tubes in providing a natural environment and rationalizing energy consumption in university computer laboratories that it can be an alternative to artificial lighting while allowing and enhancing natural light as these devices have a negative impact on thermal comfort in large areas It also found that the use of solar tubes (T.D.DS) produced acceptable SDA lighting levels and succeeded in reducing the average annual energy consumption resulting from industrial lighting as well as providing a form of healthy daylight for students in the computer lab space. She also said that buildings must be designed in different ways through innovative natural lighting systems in order to take advantage of the daylight inside, which saves a lot of building consumption for industrial lighting, as well as achieves visual and thermal comfort, and also contributes to reducing costs and helps raise student performance during the educational process.

3. Methods

A study aims to Providing the required natural lighting in innovative ways. This is done by placing tubular units on the roof of the library building in areas that lack the required lighting intensity. At the same time, these tubes are designed so that the energy does not transfer heat into the library. The tubes are characterized by their ability to transmit sunlight from Through transparent lenses that absorb sunlight falling on them, transmit them through tubes or optical fibers, and spread them within the space.

4. Definition of lighting tubes and their applications:

Tube natural lighting devices, also known as "sola tubes", are innovative daylight systems that collect natural sunlight and insert it into indoors where it may not be possible or possible to install traditional windows or sunroofs [7]. Sola tubes are a popular brand of T.D.D.S devices.

5. Features of lighting tubes and similar T.D.DS devices:

a) **Natural** lighting: T.D.DS use daylight, providing a healthier and more beautiful lighting experience compared to artificial lighting. It can significantly reduce the need for electric lighting during the day [8].
b) **Energy** efficiency: Using natural light, T.D.DS reduce reliance on artificial lighting, resulting in reduced energy consumption and associated costs.
c) **Improving** productivity and mood: Natural lighting is associated with improved mood, productivity, and general well-being, especially students in educational spaces (Abdel-Halim et al. 2021). T.D.DS bring in abundant natural sunlight, creating a more comfortable and productive indoor environment.
d) **Easy installation**: T.D.DS can be installed in various locations, including windowless rooms, corridors, or even basements of a building where it may be impossible to install traditional windows or skylights.
e) **Reduce** heat absorption: Unlike conventional sunroofs, T.D.DS reduce heat absorption by using reflective materials and advanced designs that help prevent the transfer of intense heat to the inner space, which is considered one of the best applications. Gaber et al. [9].

Overall, SolaTube and tubular natural lighting devices provide an innovative solution to bring natural light to indoor spaces, enhancing aesthetics and energy efficiency [10].

6. The most important applications:

6.1. Library Building ″ Sunnyvale Independent School District ″

The school is designed to suit the surrounding environment and use new patterns of interaction between students and teachers, as it contains nine classrooms in order to facilitate interaction and cooperation through spaces and small group rooms between classrooms and the use of many glass walls for an open and transparent design in the fields of education.

a) **Objective**: To use a new method of relying on natural daylight Fig. 1.
b) **Executing company**: WRA Architects.

Figure 16 Using lighting tubes in the inner courtyard of the Sunnyvale Intermediate School building.

The use and reliance on daylighting tubes that interact with daylight without consumption or use of energy, this building is one of the zero-energy buildings, which achieves efficiency for use in terms of integrating the elements of the building with the external environment, and this depends on the acrylic tubes consisting of fibers that retain daylight and distribute it to the spaces through the preparation of pipes Spanned.

6.2. South Whittier library:

The old library has been replaced with the incorporation of energy-saving natural lighting, creating a vibrant and safe space for the educational and cultural community Fig. 2.

Figure 17 Solatube at South Whittier Public Library.

a) **Location**: Located in South Whittier, California.
b) **Objective**: Reduce the use of artificial lighting by incorporating natural lighting throughout the library by optical fiber.
c) **The Executing Company**: Emar Studio for General Architecture.

The South Whittier Library was able to reduce electricity consumption in lighting by 38% through the use of Sola tube units, natural lighting strategies and daylighting controls, so daylight reduction were a key part of the design strategy as Sola tube played a key role in that The project also obtained LEED Platinum certification at Fig. 3. making it one of the only three buildings to have that certificate in the state.

Figure 18 Installation of solar tubes in the ceiling above the bookshelves. This will allow the evenness of natural light throughout the space via the transparent lighting tubes.

6.3. The importance of natural lighting

It can help improve the overall atmosphere of the library. Natural light can make the library feel more attractive and comfortable, which may encourage people to spend more time there. As well as in improving the health of students and library patrons [11] Studies have shown that exposure to natural light can help reduce stress, improve mood, and increase productivity [12]. Natural light also helps save energy. Libraries that use natural light can reduce their reliance on artificial lighting, which can save the user's electrical energy [13].

7. The following are some of the specific features of natural lighting in libraries:[14]

1. **Improved visual comfort**: Natural light provides a fairer and more natural distribution of light than artificial light, which can help reduce eye strain and fatigue.
2. **Increased productivity**: Studies have shown that people are more productive when they work in well-lit environments. Natural light can help improve attention and concentration, which can lead to increased productivity.
3. **Reduce stress:** Exposure to natural light has been shown to reduce stress levels. This is because natural light helps regulate the production of melatonin, a hormone associated with sleep.
4. **Improve mood:** Natural light can also help improve mood. This is because natural light helps increase the production of **serotonin**, a hormone associated with happiness.
5. **Increased energy levels**: It can also help increase energy levels. This is because natural light helps regulate the production of cortisol, a stress-related hormone.
6. Reduce the need for artificial lighting, which can save energy and cost.

8. Environmental design standards for natural lighting in library buildings

In the spaces of university libraries, navigation is key. To find the right shelf and book, vertical lighting of at least 200 lux is required as shown in Table 1. High beam uniformity ensures that books on shelves are equally visible at any height. Recommended shelving lighting systems include asymmetric lighting installed above each shelf, but linear pendants or wall-mounted luminaires with asymmetric light are also recommended options [15].

Reading areas in libraries need powerful working lights. The minimum average illumination should be 500 lux with high homogeneity and low glare as shown in Table 1. This can be efficiently achieved using lighting with indirect and direct light. [16] For greater flexibility and to suit individual needs, important lighting with asymmetric lighting that reduces glare is recommended for each reading table – preferably integrated into the tabletop to save space [17].

Table 1 Lighting requirements for libraries according to the International Organization for Standardization

Lighting requirements in EN 12464-1:2021

Type of task / activity area	Lux-level (E_m)		Glare rating (UGR_L)	Uniformity (U_0)	Colour rendition (R_a)	$E_{m,z}$	$E_{m,wall}$	$E_{m,ceiling}$	Specific requirements
	required	modified				$U_0 \geq 0,10$			
Library: bookshelves	200	300	19	0,60	80	-	-	-	Vertical illuminance on shelves
Library: reading areas	500	750	19	0,60	80	100	100	50	

8.1. Egyptian Code Requirements

The Egyptian Code for Public Building Regulations [ECRPB] specifies lighting requirements for libraries and the following are the basic requirements [18]:

1. **Illuminance**: The minimum working-level illumination [the surface where people read or write] should be 300 lux according to Egyptian Code Requirements as shown in Table 2, But the required illumination should be 500 lux as shown in Table 1.

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2. **Uniformity**: The luminance regularity should be at least 0.7. This means that the difference in luminance between any two points at the working level should not exceed 30%.
3. **Glare**: The glare indicator should not exceed 19. This means that the glare generated by lighting must not be too bright or dispersed.
4. **Colour rendering:** The Colour Show Index [CRI] must not be less than 80. This means that lighting must accurately reproduce the colours of objects in the library.

- **ECRPB** also specifies that lighting should be evenly distributed throughout the library. This means that there should be no dark spots or areas where the lighting is too low. Lighting should also be free of shadows and glare.

Table 2 Level of lighting intensity in libraries according to the Egyptian code

Intensity of illumination **Lux**	location	
	bookshelves	libirary
300	used	
60	unused	
	index work	
1000	map spaces	
300	copy rooms	
	Reading	
300	desk reading	
300	projection	
60	Microfiche reading	

9. Daylight measurements:

Daylight meters are used to measure the amount of daylight entering a building and its impact on the user. They are important for the design of energy-efficient, comfortable and hygienic buildings [19].

9.1. Some common metrics of natural light include: [20]

1. **Daylight factor [DF]:** The ratio of illumination at a point inside a building to illumination on a horizontal surface outside the building. Higher DF indicates more daylight in the building.
2. **Spatial daylight autonomy [SDA]:** The percentage of time during a typical year in which a specified light level is reached or exceeded at a given point in the building. A higher SDA indicates that a building is more likely to be naturally lit.
3. **Daylight glare probability [DGP]:** The likelihood that a person will feel glow from daylight in a building. A low DGP indicates that a building is less likely to cause glare.

9.2. Here are some additional benefits of using daylight meters in building design:[21]

- **Reduce energy consumption**: Daylight can help reduce the need for artificial lighting, which can save energy and cost.
- **Improve the health of students and visitors**: Daylight has been shown to improve the health of students within the library by reducing stress, improving mood, and increasing productivity.

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- **Increased sense of** satisfaction: Daylight can increase students' satisfaction with their study environment, which can lead to lower boredom rates and increased productivity.

10. Selection of the case study "A case study of a library illuminated in a natural manner “:

The selected case study is a one-floor library truss building in the middle of the buildings of the Higher October Institute of Engineering in Sixth of October City with an area of 300 m2, as shown in Fig. 4 The height is 6 m, the library is in the middle of the building where it is 3 m from the sides and 2 m from the back with external windows as shown in Fig. 5, the existing windows In the side areas between the building and the library while the back side of the library is completely opaque.

Figure 19 map for location of the Institute and determine the location of the library building, its dimensions and the corridors surrounding the library.

Reason for choosing the building:

The library building is located in the middle of the campus and is thus considered in a privileged location for access from all directions and is considered the best place to study, read and use computers, and thus it is intended for many students from all departments, but it lacks natural lighting in some places because it is surrounded by the institute's buildings from three sides, which reduces the percentage of lighting significantly within the different spaces of the building.

Figure 20 (a) the location of the library building with a trussable structure in the middle of the campus and the places of the windows, (b) the shelves area inside the library and the lack of natural lighting to reach the area and no artificial lighting.

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Choosing the environmental analysis software Climatestudio "DIVA"

Computer simulations are used to evaluate the performance of proposed passive daylight techniques. Initially use Rhinoceros to make the model. Then use Climatestudio, the fastest and most accurate environmental performance analysis software for architects and construction engineers. Simulation workflows help designers and consultants optimize buildings for energy efficiency, access to natural light, artificial lighting performance, visual and thermal comfort, and other measures of the health of space users. ClimateStudio is an extension to Rhinoceros 3D and is the updated version of the DIVA environmental analysis tool.

Figure 21 Different measurements within the viewing area showing the achievement of the required levels of natural light by “DIGITAL LIGHT METER”.

Measurements were made using a digital light meter in areas with high occupancy to identify deficiencies, areas of poor lighting, as well as areas of glare intensity as in Fig. 6.

It is evident in the library in the shelving area and the low level of lighting in it as in Fig. 7 and shown in Fig. 8 the field measurements that were taken by the devices in the shelving area of the library.

Figure 22 The shelving area of the library and its low illumination level

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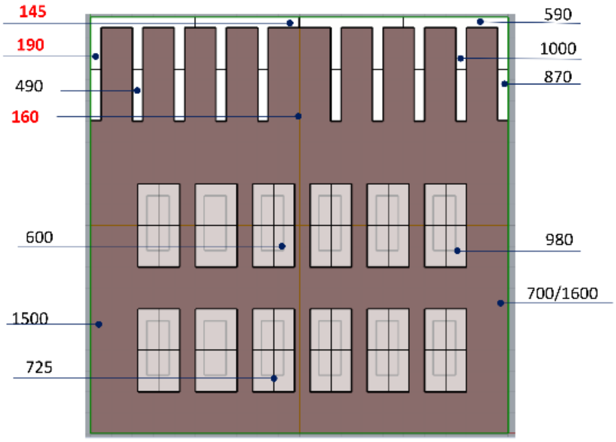


Figure 23 Field measurements in different areas within the library using an intensity meter

Measurements were taken for the different areas within the library, in which the intensity of lighting was measured [computer area - reading area - registration and indexing area] as well as Fig. 9.

Figure 24 Pictures of the different areas within the library at the entrance and at the computer area

10.1. Studying the extent to which the code standards are achieved for the provision of natural lighting:

Through the field study, it was found that the code requirements and natural lighting standards were met in the viewing area, which ranges from 500 to 750 lux as in Fig. 10. While a severe decrease in natural lighting levels was observed in the shelves area at the back of the library with no compensatory artificial lighting as in Fig. 11.

10.2. Current situation measurements using environmental analysis software

The Luminous intensity level measurements were taken using the environmental analysis software ClimateStudio showing the areas where the required Luminous intensity levels are low, which is the area of the rear shelving as in Fig. 10.

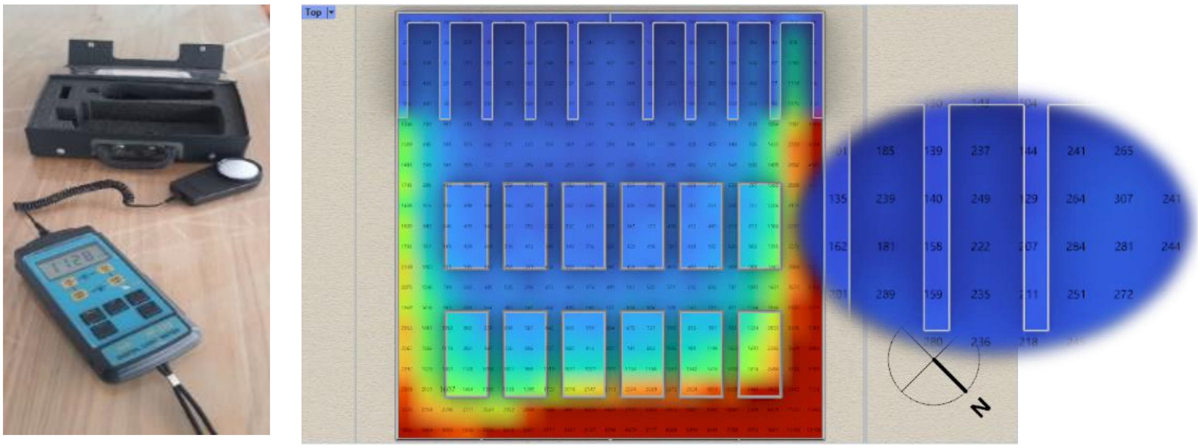
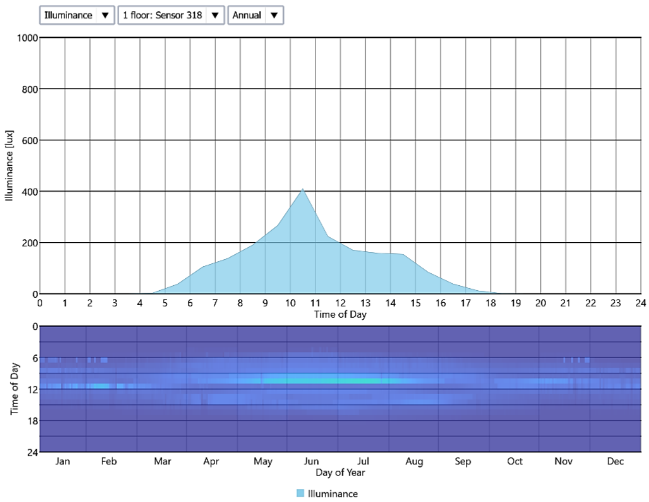


Figure 25 Luminance level measurements - Measurements that meet the design standards using the light intensity device.

The following graph shows the low level of natural light in the library's shelves area during the year as in Fig. 11.



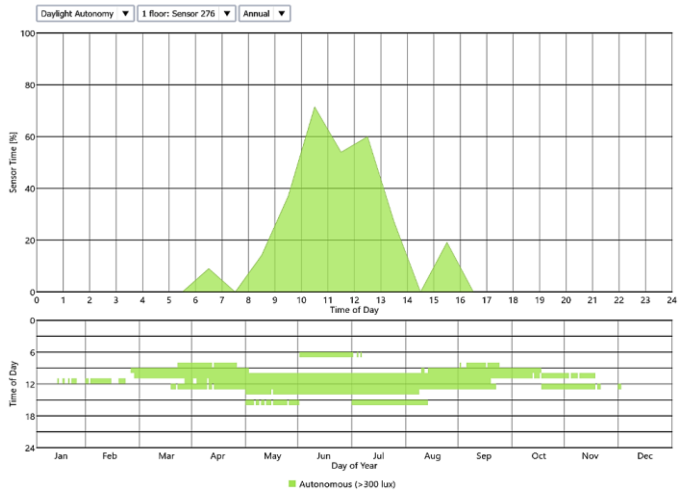


Figure 26 Graph of the level of natural light in the shelving area **Figure 12** A graph showing the annual low SDA ratios in the shelving area exceeding 300 lux.

10.3. Spatial Daylight Autonomy [sDA] for library:

Refers to the proportion of the consistently used floor space that receives natural daylight. In this framework, areas considered to have "daylight" are those that achieve desired brightness levels [300 lux] using only natural light for at least half of the time they are in use. Such areas are classified as having 50% daylight autonomous [22]. The computation of sDA involves yearly, climate-dependent simulations encompassing a multitude of sky conditions over the entire year as shown in Fig. 12,13

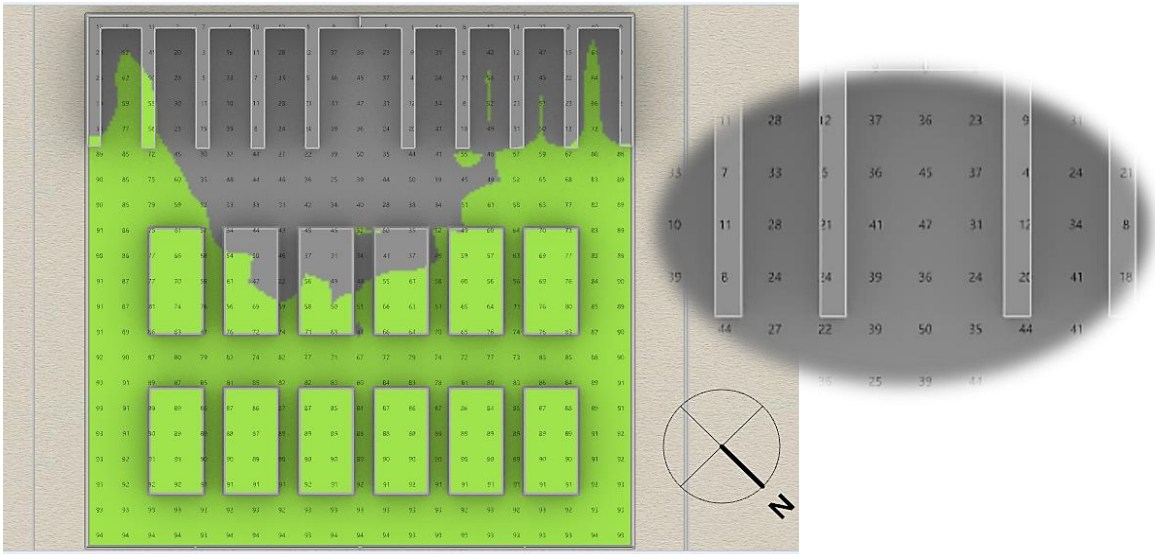


Figure 13 Measurements of the amount of natural light located over a given area within the library - SDA for the base case.

10.4. Annual Sunlight Exposure [ASE] for library:

The proportion of the normally occupied area that is "overlit." In this context, "overlit" areas are those that have more than 250 occupied hours of direct sunlight [>1000 lux directly from the solar disc]. It is important to note that whereas sDA considers the operation of dynamic shading, ASE is computed for the dynamic shading system fully open throughout the year. This difference, which may be confusing, aims to promote passive design methods that reduce discomfort from the heat and light without relying on manual shade operation as in Fig. 14.

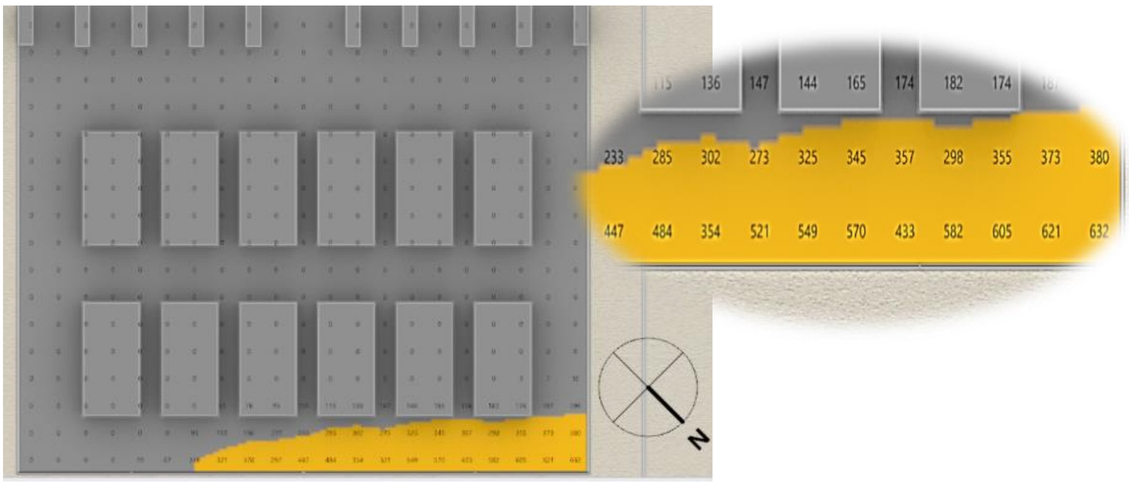


Figure 14 Measurements that determine the ASE inside the library for covered areas exposed to direct sunlight annually and exceeding 1000 lux.

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10.5. Comparison between field measurements and measurements through the environmental analysis software

It was clear through the measurements of the analysis program when compared with the results of the field that there is a small difference in the measurements, the average measurements at the first table was 980 lux and in the program 902 lux by 0.7 and in the middle of the shelves area for the area that lacks lighting the average measurement of the program was 225 and field measurement 160 with a difference of 0.6 between the two readings.

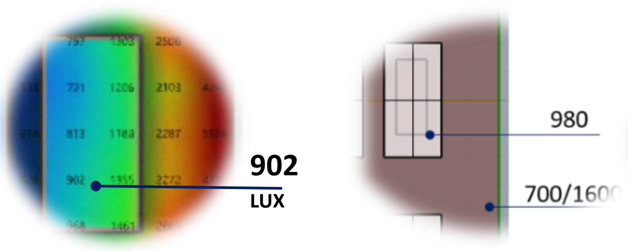

Figure 15 The difference between field measurements and using the analysis program at the first table in the side entrance of the library.

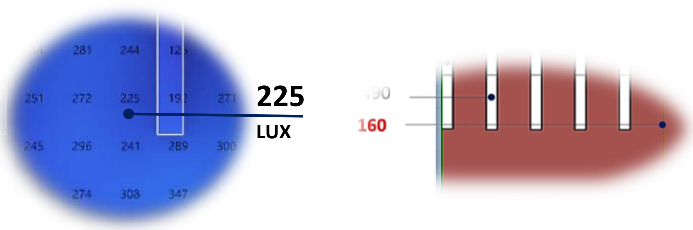

Figure 16 Example of the measurement difference at the shelf area

10.6. Proposals to improve library space performance [Using Tubular Daylighting Devices "SolaTube"]

Solatube Daylighting systems are a new way to harness daylight. The ancient Egyptians used a tubular daylight device that uses a reflective material [23]. Nowadays, this method has attracted wide attention all over the world. Tubular daylight fixtures collect enough sunlight to light up without electricity. It is a good choice for some places that do not have windows to transmit sunlight. Today, tubular natural lighting devices are widely used, such as: rooms without windows, tunnels, underground parking, corridors, etc.

The SolaTube natural lighting unit consists of a collector or receiver converter and a diffuser for the daylight inside the library. The principle of a tubular daylight device is that the light collector collects a large amount of natural light, passes the light through a tube, and is reflected several times into the tube to change the direction of propagation of sunlight. Diffused light hits down into a vacuum [24], bringing light to the library. As follows at Fig. 17.

Figure 17 Components of natural tubular lighting units

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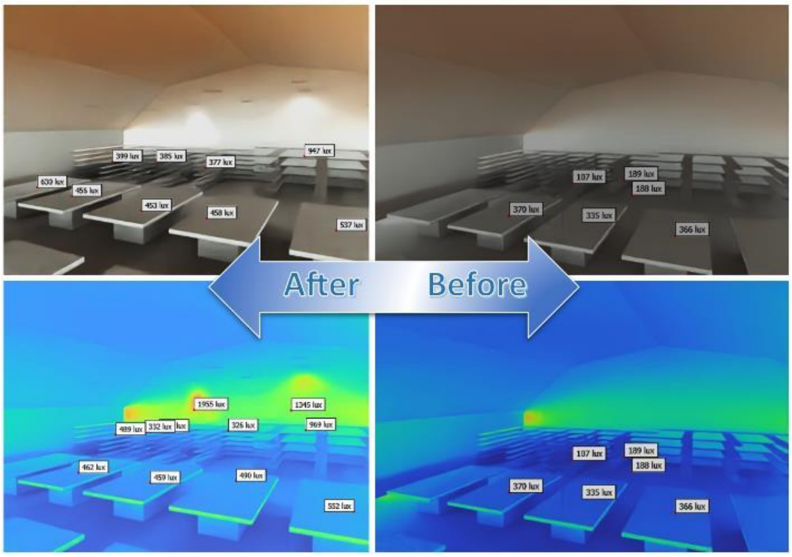

Figure 18 Shots of environmental analysis program readings and library space simulation before and after installation of sola tube Natural lighting tubes.

10.7. Comparison between the base case and the case of adding solar tubes:

When using SolaTube, levels of light intensity were reached in dark areas of up to 500 lux, and this is what international measurements require in the shelves area [dark area], while in the same area they ranged from [120 and 145] lux, which shows the benefits of using SolaTube in transferring natural light into the space.

After making the library model on the Rhino program and adding the environmental analysis extension ClimateStudio, the program's readings after the simulation work before installing the SolaTube showed levels of lighting intensity ranging from 107 to 190 lux in the shelves area and from 335 to 400 lux and after installing the light tubes, the standard levels were achieved, as the readings in the shelves area reached 500 lux as well as on table surfaces that did not achieve the standard levels of lighting intensity required to provide visual comfort inside the library.

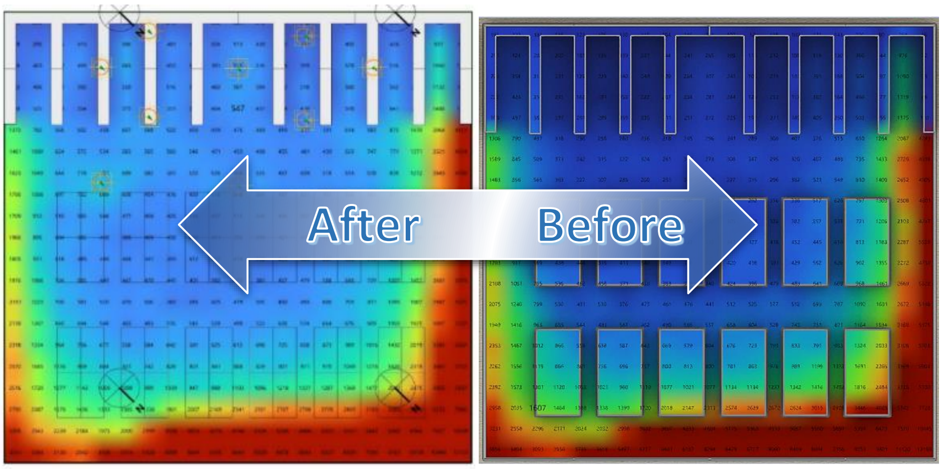

Figure 19 Comparison of measurements of light intensity for the base case and after the installation of SolaTube light tubes at the back of the area that is poor for lighting and access to international and local standards of natural light intensity inside the library.

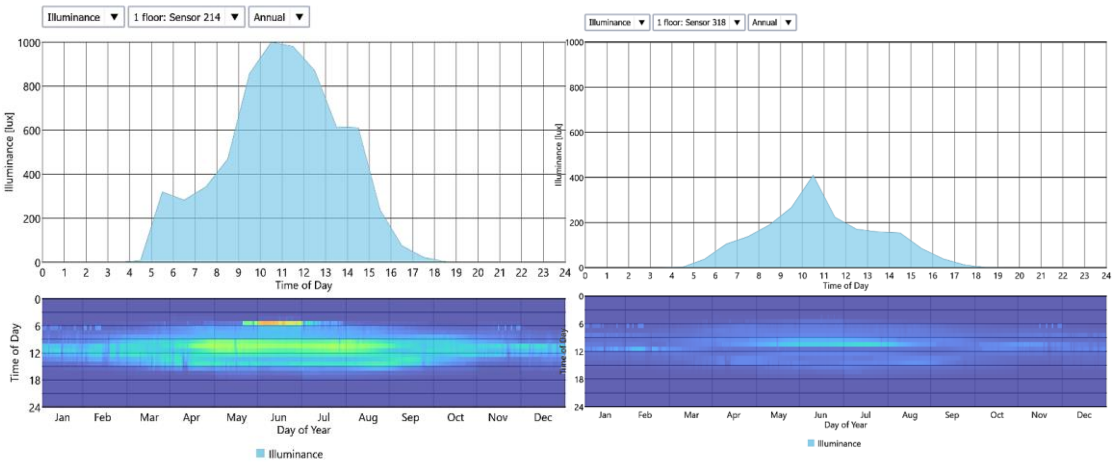

Figure 20 A graph showing the difference between the light intensity levels during the year for the library before and after installing SolaTube in areas where the intensity of illumination is below the required limit.

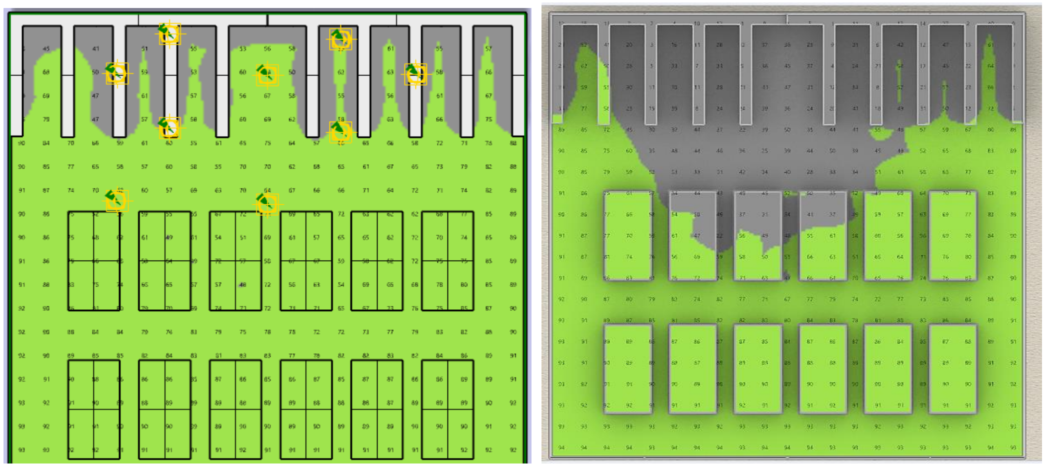

Figure 21 Measurements of the amount of natural light located over a given area within the SDA library for the base case and after the addition of light tubes.

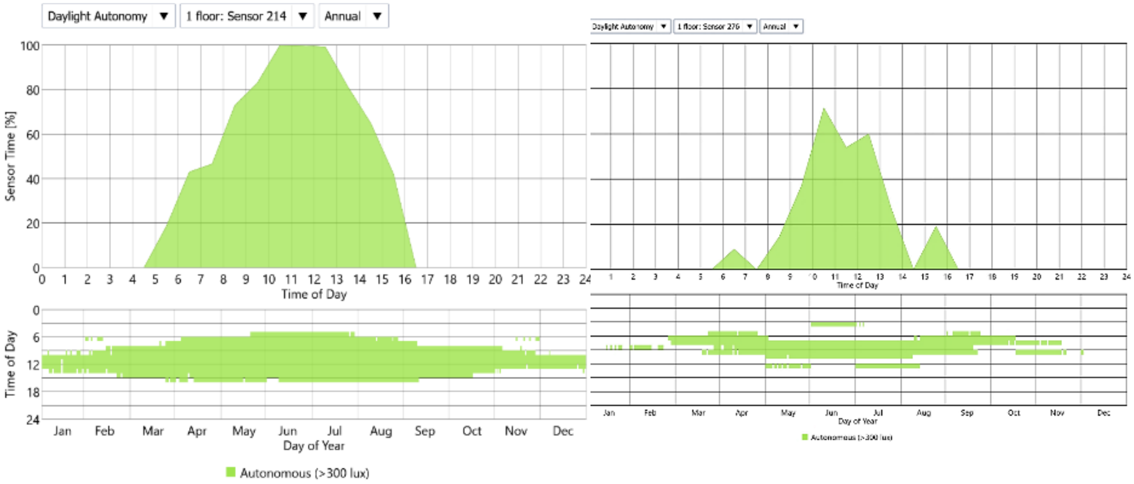

Figure 22 Graphs show the difference in the annual low SDA ratios in the shelving area, which exceeds 300 lux for the two cases before and after adjustment.

11. Results

We found from the research study that:

a) It is easy to connect the internal spaces with the surrounding external environment using modern methods.
b) An isolated dark room can be transformed into a room filled with natural light.
c) The use of SolaTube had a direct impact on the levels of natural light intensity compared to non-use of tubes.
d) It has become possible to transfer natural lighting inside the space without transferring thermal loads and thus maintaining the temperature inside the space and not needing additional energy for cooling, and this is what happens when using traditional methods to introduce natural lighting inside the library, such as upper openings.

12. Discussion

The implications of the findings in the context of existing research are that the use of SolaTube, an optical fiber tube, can effectively improve the levels of natural lighting in areas with low illumination. This is important for achieving visual comfort and productivity in spaces such as libraries. The study found that SolaTube was able to meet international standards for lighting intensity in the shelves area of the library, which was previously poorly lit. The use of SolaTube also has advantages such as easy installation and maintenance, reduced heat absorption, and energy saving. As for the limitations of the study, it is important to note that the research focused on a specific library and may not be directly applicable to other spaces or buildings. The study also did not explore the long-term effects or potential drawbacks of using SolaTube, such as glare or potential damage to the comfort of occupants. Additionally, the study did not investigate methods to control the amount of illumination provided by SolaTube, which could be an area for future research.

13. Conclusions

The most important advantage of using solar tubes is:

a) Improve productivity and mood.
b) Easy installation and maintenance
c) Reduce heat absorption.
d) Reduce the use of energy as it transmits natural light without relying on electrical energy and with no heat transfer, thus contributing to maintaining the temperature inside the space.

The use of optical fiber tubes achieved the levels of lighting the amount of natural lighting according to international standards in the back area of the library subject of the research problem, and the types and number of tubes required were chosen to avoid reaching lighting levels higher than the standard and thus cause glare and damage to the comfort of students and library occupants and provide a healthy environment and psychological comfort that stimulates concentration and study. Also, these pipes are considered an economical solution, whether the cost of purchase, installation or even maintenance, and for their unique design, they transmit natural lighting at equal levels of illumination, however, they do not transfer thermal energy to the vacuum due to the thermal insulation in them. In the future, these tubes are likely to provide methods to control the amount of illumination to ensure the highest degree of visual satisfaction and contribute to the sustainability of buildings.

List of abbreviations

SDA: Spatial Daylight Autonomy
ASE: Annual Sunlight Exposure
DF: Daylight Factor
DGP: Daylight Glare Probability
ECRPB : The Egyptian Code for Public Building Regulations
T.D.DS: Tubular Daylighting Devices

Declarations

1 Ethics approval and consent to participate

This research did not involve human participants. Therefore, ethics approval and consent to participate were not applicable.

2 Consent for publication

All authors consent to the publication of this manuscript and take responsibility for its content. It has not been published previously, nor is it under consideration elsewhere.

3 Availability of data and material

The data and materials supporting the findings of this manuscript are available upon request from the corresponding author.

4 Competing interests

The authors declare that they have no known competing financial interests.

5 Funding

No Funding

6 Authors' contributions

- Conceived and designed the analysis: HK
- Collected the data: AM
- Contributed data or analysis tools: AM
- Performed the analysis: HK
- Wrote the paper: HK, AM

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