Retrofitting of deep educational studios by integrating natural illumination

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ABSTRACT

Daylighting is a fundamental resource that enhances visual comfort and reduces energy consumption in buildings; also, it improves occupant's health and well-being. Deep studios consume artificial lighting and energy to achieve the target lux for educational buildings in Cairo, so this paper aims to enhance the daylighting in deep educational studios to decrease energy consumption, save energy, and make the building more sustainable. Many lighting strategies can be used to increase the dependence on daylighting in deep spaces some of them are traditional illumination Systems like courtyards, atriums, and skylights, and others are modern illumination Systems such as light shelves, solar tubes, light pipes, and optical fibers. The methods of this research depend on using a Lighting simulation program (Dialux) to examine the integration between natural and artificial lighting strategies to enhance Lighting performance and energy saving, and it is also used to optimize the best strategy from lighting retrofitting alternatives for educational studios. The results show that the best strategy is using a light shelf that reduces glare beside windows and lets the light penetrate in the deep parts of the space with a skylight that illuminates the central part of the space.

1. Introduction

Buildings consume around 60% of the produced electricity worldwide [1]. It consumes energy to provide the space with cooling, heating, and lighting systems to be more comfortable for human beings, which is considered a major energy demand, so if its design is taken into consideration, it will save more energy.

Daylighting is a fundamental natural resource that can enhance the indoor environmental quality, occupant's health, and wellbeing [2], by providing visual comfort for the users. On the other hand, it reduces electric energy consumption, saves energy, and supports building sustainability [3].

Recently lighting energy consumption has been the main issue in educational buildings more than any other building typology, especially in deep studios, so the concept of daylighting integration in educational studios has taken a level of interest in the researcher studies in the last few years [2] [3] [4].

Studies show that there exists a direct link between student performance and the presence of natural daylight in working spaces like architectural design studios [4], so it was essential to provide a certain level of illumination around 500 lux [5] and it was also linked directly to the amount of

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energy consumption as the existing deep studios have a high level of consumption [3] [6] to provide the requested luminance level. According to daylighting conditions, an area is considered deep when the ratio of depth to ceiling height is greater than 2.5 percent. This shows that the depth of the space is greater than what is recommended to provide for the optimal possible natural illumination and daylight penetration. and it was calculated using the following formula: The ratio of depth to ceiling height is equal to the depth of space / ceiling height.

Finally, integrated daylighting with deep studios can create a pleasant space for the student [7]; improve the quality of teaching, increase productivity & attention, promote better student health, reduce energy consumption, and enhance building sustainable requirements [4] [5].

From the above, this research aims to enhance daylighting illumination Systems in deep studios and optimize the best retrofitting alternative for visual comfort with less energy consumption. As in Cairo, many universities consumed more energy to provide lighting to space [8]

2. Research objectives.

The main objective of this study is to investigate various lighting strategies, both traditional and modern, that can be utilized to increase the reliance on natural daylight in deep studio spaces. This includes an assessment of design approaches such as courtyards, atriums, skylights, light shelves, solar tubes, light pipes, and optical fibers. Moreover, it determines the optimal daylighting integration approach that can reduce glare, maximize light penetration into the deep areas of the studio, and illuminate the central portions of the space.

3. Research methodology

The research methodology is divided into two parts theoretical part and deductive part. The theoretical part is illustrated in literature review of method of applying daylighting, daylight strategies integration, and lighting simulation program methods. Secondly, the deductive part is considering the piolet case study, which is deep studio in Cairo university faculty of engineering architecture department and apply daylighting retrofitting strategies that enhance the dependence on daylighting in deep studios such as light shelf, inclined light shelf, and skylight. As shown in Fig.1.

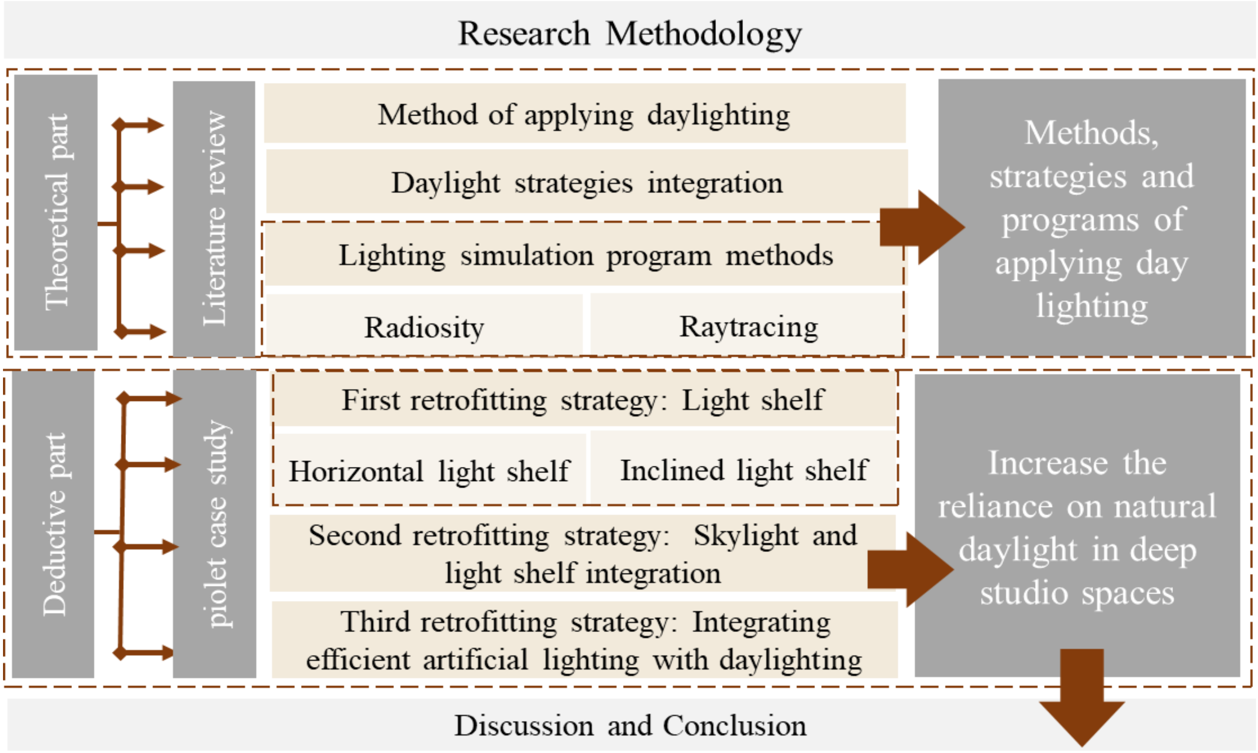

Fig. 1. Research Methodology

4. Literature Review

While the daylight enhances the visual contact between the inside and outside [7], and give a pleasant space for students in their working environment. However, natural daylight has an important role in improving student's alertness and performances [9]. Also, the strategies used for providing daylighting in deep studios can reduce consumption and save energy, so it enhances sustainability.

In classrooms, the expected level of illumination on the desk plane according to international standards: European and North American standards are equal to 300 lux. That will be more applicable to the type of study activity like writing and reading, but for design studios and on the board the required illumination is around 500 lux which needs more electrical energy to reach that level [3] [10] [11].

Daylight factor is one of the measurement tools for daylight that equals the Summation of three main components: first, the sky component which is related to the direct daylight provided from the sky. Second, the externally reflected components are generated from the reflection of the external surface from the sky to other buildings. Third, the internal reflection generated from the reflection of the skylight on the internal surfaces [12]. This tool appeared in much research to calculate the lighting distribution in space.

4.1 Method of applying daylighting

There are many illumination Systems for applying and utilizing daylighting in educational design studios. Those methods can be categorized into traditional illumination Systems such as Windows, court, atrium, and skylight, and modern illumination Systems like a Light shelf, solar tube, and optical fiber.

Windows is one of the essential building components that provide the spaces with daylighting and enhance well-being and health with sunlight penetration. So, its design affects the building demands for cooling, heating, and lighting [13] as shown in Fig. 2. Many energy codes and policies set regulations for the window-to-wall ratio percentage.

Also instead of using windows only, merging the building design with a proper courtyard or atrium will improve building energy efficiency and enhance lighting distribution inside the space [12], as the atrium allows daylighting to penetrate the center of deep spaces [14] as shown in Fig. 3.

Another way to enhance daylighting in the building is the skylight strategy which lets the artificial electric light turn to save energy. In a study launched to ask about the effect of skylights on employees, the skylight floor workers rated the highest satisfaction for light distribution quality with 96% while the others on floors with windows were only satisfied with 67%.

A light shelf is one of the most important strategies to enhance natural daylight in deep spaces. It appeared in many kinds of research to obtain its suitable orientation, position, and size. Meresi [4] examined those issues and suggested movable semitransparent blinds combined with a light shelf with an inclination between 10◦ and 20◦. which provides the educational space with uniform lighting distribution without glare near windows and enhances the light level at the back of the space.

Also Hashemi & Theodosiou [15] [16] showed that the light shelf is effective in deep educational spaces, and when it was combined with shading louvers it could avoid excess solar radiation, and it can be transparent to reduce glare, so it makes the lighting distribution more comfortable for students working desk space as shown in Fig. 4.

Another way to improve daylight distribution in space, especially in the crowded urban fabric is optical daylighting systems. They capture natural daylight and then direct the light to space by a series of pipes or mirrors optically with a lighting level of around 500 lux [5] as shown in Fig. 5. Dutton [17] examine a ray tracing software to simulate the path of light in the pipe system, also to predict its performance and it is proved that this method is more efficient than a mathematical one.

The mirror system also is effective in enhancing daylight by reflecting the light and directing it to the needed space; also merging pipe and mirror systems can increase the amount of daylight from 11 to 15 times.

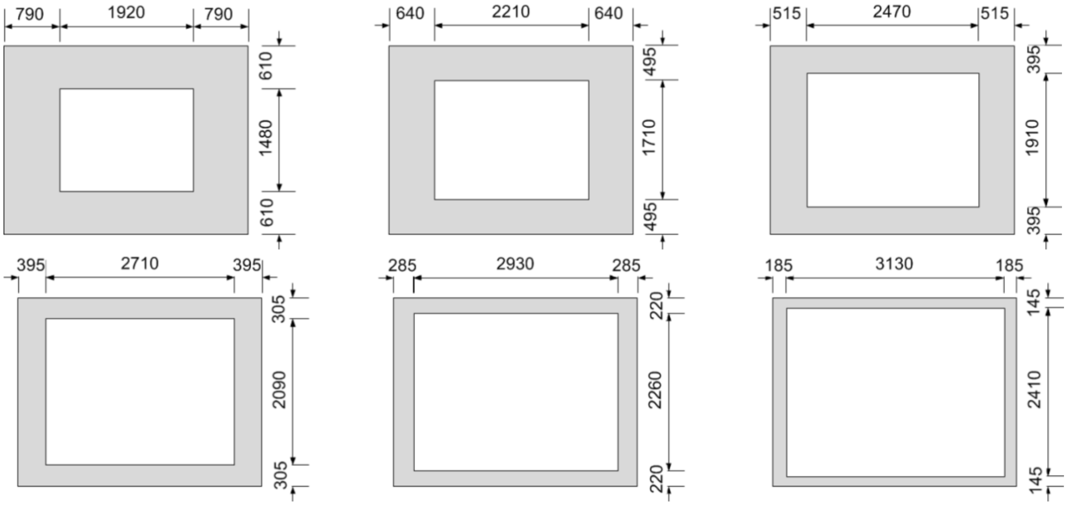

Fig. 2 Elevation view of the window wall, with WWR of 30%, 40%, 50%, 60%, 70%, and 80% [13]

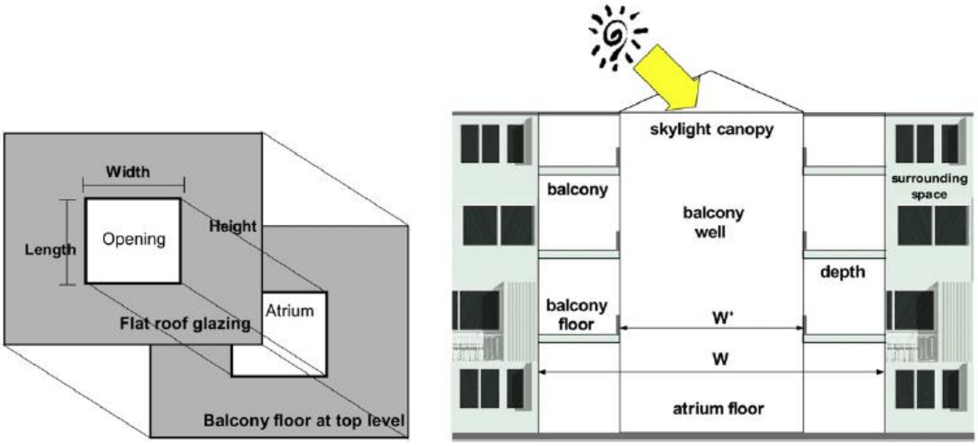

Fig. 3 Well index in atriums [14]

Fig. 4 Louvres in light-shelf (left) and sunshade (right) modes [15]

Fig. 5 A typical light pipe [5]

4.2 Daylight strategies integration

Many retrofitting strategies and building environmental designs use these methods to enhance natural illumination, for example, in College ‘La Vanoise’, Modane, France; the building needs no artificial lighting. The designer makes tilted glazing on the south facades to reduce glare and heat gain in summer while making stainless-steel external light shelves to reflect sunlight into the classroom in winter. The designer also makes a skylight on the roof with a triple-layer transparent polycarbonate. Every classroom is lit from both sides, either directly or through the atrium.

Another building that applies daylighting illumination Systems is Infante D. Juan Manuel Health Centre, Spain. The designer used Light wells, a vertical shaft in the center of a building used to bring daylighting to the lower floors - glass block flooring, and small light shelves on the external windows. By using these ways, the building makes many energy savings. [18]

Maier [19] also examine a retrofitting lighting strategy by changing the existing window of an apartment of a residential building with a French window, which has a larger window area. The simulation proves that the daylight factor (DF) increases from 1.92% to 2.48% and the energy consumption decreases from 165 kWh/m2/y to 126 kWh/m2/y by changing the window size.

There is great potential for using lighting simulation programs in the architectural design process. Architects must be aware of dealing with these programs. That will certainly contribute to producing specific professional architects, who are aware of the importance of Daylighting and energy efficiency concepts and illumination Systems. [20]

Different retrofitting scenarios were established in two universities in two different countries, one in Stuttgart and the other in Konya. The solutions here depend on artificial and daylighting that is about changing the type and number of the luminaires and making a daylight and occupancy control system. There is a significant reduction in energy demand by utilizing energy-efficient lamps In Konya. While a higher reduction in energy demand was observed in Stuttgart, by using eight efficient luminaries instead of 15. [21]

4.3 Lighting simulation program methods

There are two calculation methods used by lighting simulation programs to calculate the illumination in the space one of them is called radiosity and the other is called raytracing.

4.3.1 Radiosity

The radiosity method is used to determine the exchange of radiant energy between surfaces. [22]It is a calculation method that divides each surface into small pieces, called patches. Each patch is calculated for light that lies on the surfaces individually. The programs that used this method solved the equations in the model by determining the quantity of light on each patch. The radiosity method can calculate the model once and produce the needed view. [21]

Superlite is one of the first daylighting simulation programs that worked with this method.

4.3.2 Raytracing

The raytracing method determines the visibility of surfaces by tracing imaginary rays of light from a person's eye to the corresponding objects. [22] It is a specific point lighting calculation process. This method also works for all model types including translucent, transparent, and specular surfaces. It also creates a beautiful rendering image by visually representing light on the surfaces. [21]

Examples of the programs that worked with this method are Radiance, Genelux, and Passport. Some programs worked with both methods like Dialux, AGI32, and Lumen Designer. After all, the most recent trend in environmental control studies is to simulate the building performance to assess and select the best alternative in the design process, for daylighting simulation the main programs that appeared in the previous studies are (Dailux, Relux, and Radiance), [22] Dailux is available for free to let the users design the optimal internal lighting distribution for space, both Dailux and Relux can download catalogs from the electrical companies and then provide a photorealistic image. Editing the parameters of luminaire type, lamp color, and mounting height also allowed illuminance contours View On the desk level

5. Methodology

The paper examines the ability to utilize daylighting in deep studios using the Dialux lighting simulation program, which simulates different lighting retrofitting strategies that are divided into traditional and modern illumination Systems like windows, light shelves, and skylights. To demonstrate how much these methods may help deep studios rely on daylighting. Also, examine the integration of daylighting and efficient artificial lighting and make an optimization to reach the optimum strategy. The research will examine the daylighting through daylighting factor metric which measure the daylight availability that contrasts the amount of daylight present within a room under normal working conditions with the amount of daylight present outside under cloudy conditions. The process was conducted in a studio in an architecture educational building at Cairo University faculty of engineering. A brief description designed for the proposed building is shown in Table 1.

Table 1 Brief description of the proposed building.

Issue	Description
Location of	Egypt
Building type	Educational
Orientation	North-south
Studio function	Design Studio
Studio dimensions (m)	(45L*29W*4H)
Openings	Single glazing
Simulation program	Dialux lighting simulation program
Lighting system	Led luminaire
Sky type	Clear sky
Maintenance factor	80%
Reflection factor	Ceiling70%, wall50%, floor 20%

6. Piolet case study

Deep Studios' architectural design suffers from a shortage of natural light across the building, due to the existence of the daylighting near the window and the leakage of it in the central area of the space, which leads to increased reliance on artificial lighting thus increasing energy consumption. The paper aims to increase the dependence on daylighting in educational design studios to be more sustainable, healthy, and decrease energy consumption. So, the research suggests some lighting retrofitting strategies for deep design studios to enhance daylighting and reach the required illumination lux which was 500-750 lux.

Firstly, the studio's natural illumination was simulated using Dialux a lighting simulation program- in its existing situation to measure the daylighting illumination (lux) in the whole space. The results illustrate the lighting distribution in the space and find that the illumination level is higher than the required illumination near the windows with glare, and there is a leakage of the illumination level in the middle of the space due to the deepness of the studio as shown in Fig.6. Also, it notices that the level of illumination on the south façade is more than the other facades.

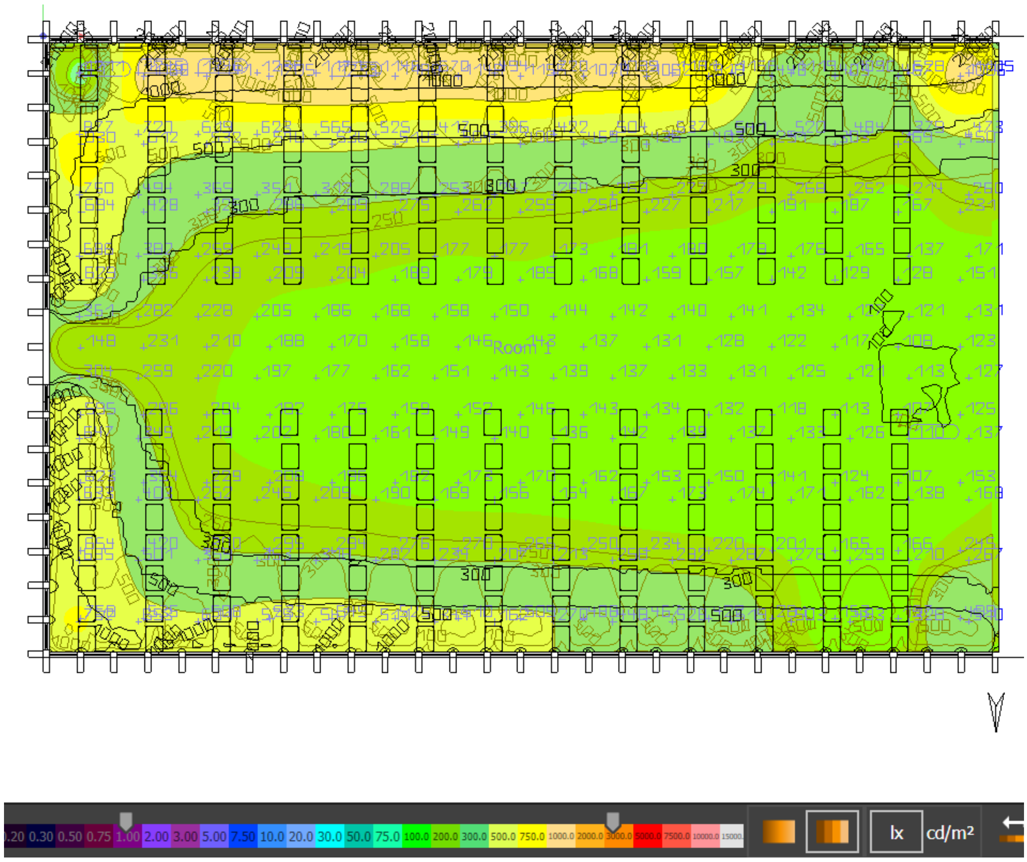

Fig. 6 Lighting distribution in the design studio using Dialux simulation program source: authors.

Another simulation for the actual situation is the integration between daylighting and existing artificial light; it shows that the level of illumination near the windows increased without any need but in the middle of space the level of illumination became corresponding to the required illumination as shown in Fig.7.

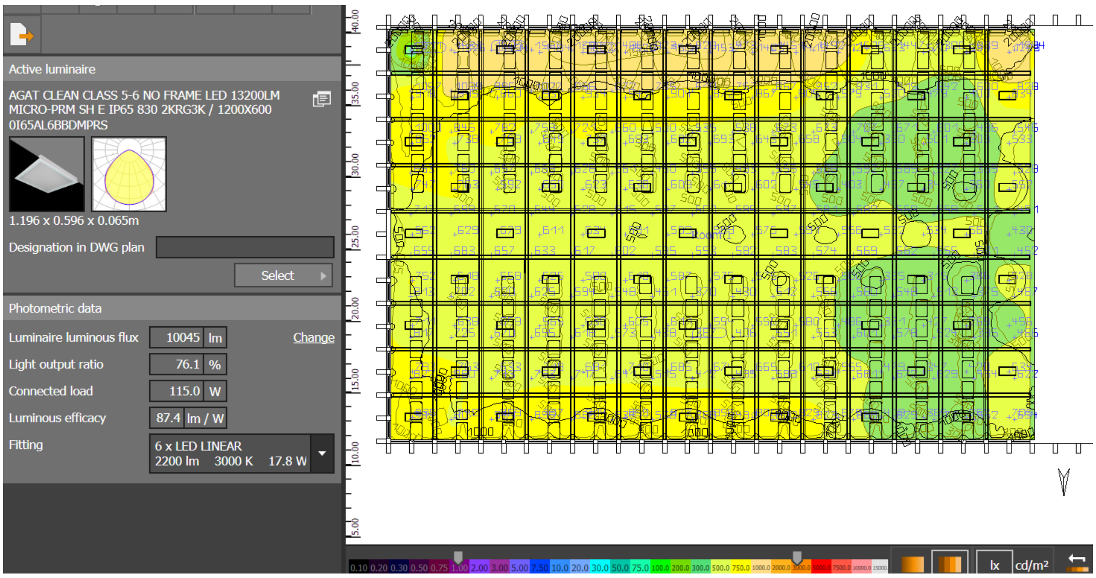

Fig. 7 Artificial and day Lighting distribution in the design studio using Dialux simulation program source: authors.

6.1 First retrofitting strategy: Light shelf

There are two ways of applying a light shelf in the building. The first method uses a horizontal light shelf with a high reflection factor, and the second method utilizes a light shelf with a different inclination angle. The research makes two different simulation scenarios to evaluate the most suitable light shelf position. One is a horizontal light shelf, and the other is an inclined light shelf with an inclination angle.

6.1.1 Horizontal light shelf

Horizontal light shelves are added in the transaction of the windows with a 90% reflection factor in the 3 facades; north, east, and south to decrease the glare near the windows and increase the level of illumination in the deep parts of the space as shown in Fig. 8.

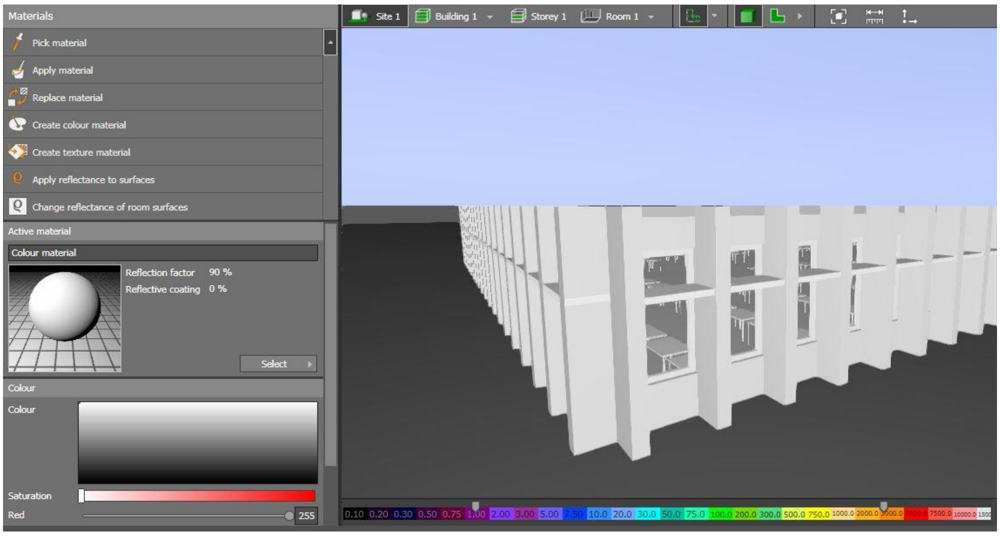

Fig. 8 The studio after adding light shelves and the reflection factor Source: authors

This strategy improved the distribution of illumination near windows as it reduced the glare level and achieved the target illumination for studios. But its affection in the middle is very low as shown in Fig.9.

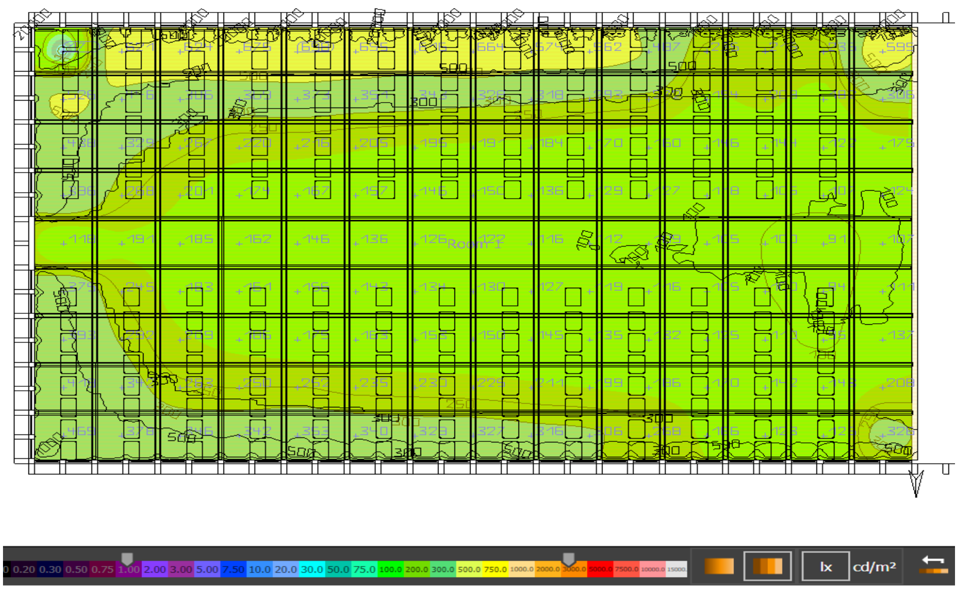

Fig. 9 Lighting distribution in the space after adding light shelf using Dialux simulation program source: authors

6.1.2 Inclined light shelf

As it appeared in many kinds of research that the light shelf angle of inclination is important, the second strategy is to examine the light shelf with angle = 15 ^{0}. The results showed that the inclined strategy was better in the lighting distribution than the horizontal one as shown in Fig.10.

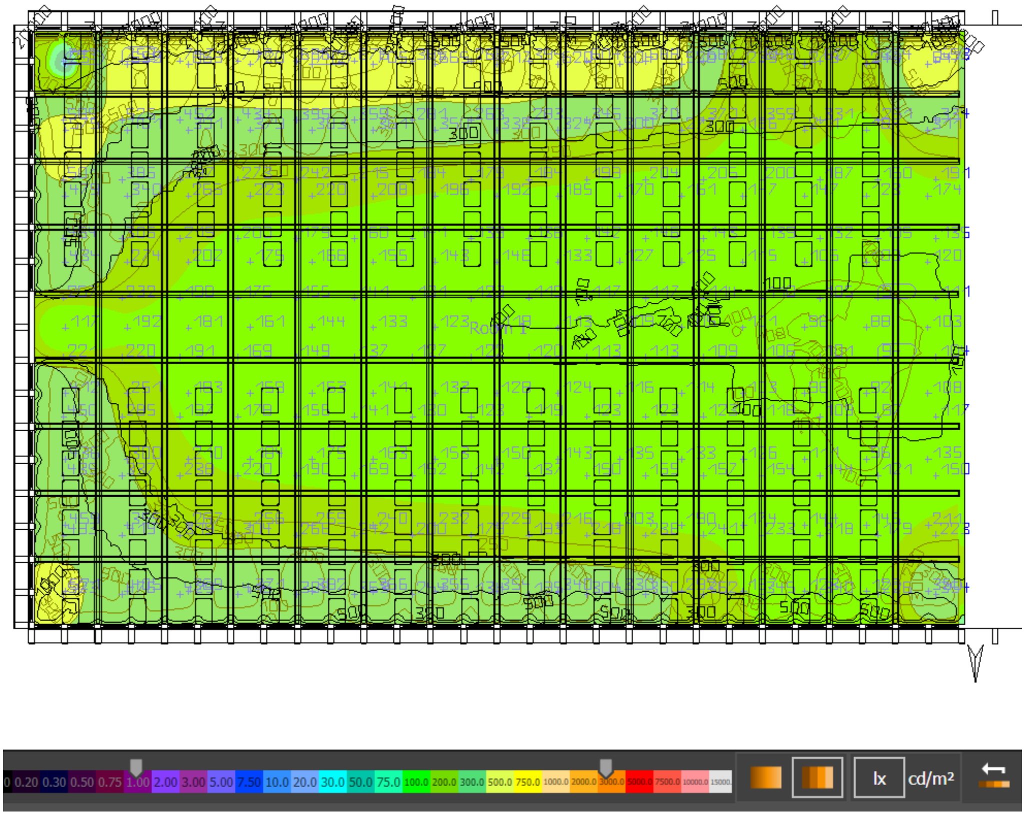

Fig. 10 Lighting distribution in the space after adding an inclined light shelf using Dialux simulation program source: authors

6.2 Second retrofitting strategy: Skylight and light shelf integration

The second retrofitting strategy is integrating the light shelf with the skylight in the center area of the space which has the minimum illumination lux as shown in Fig. 11. So, it will increase the illumination in the center of the design studio.

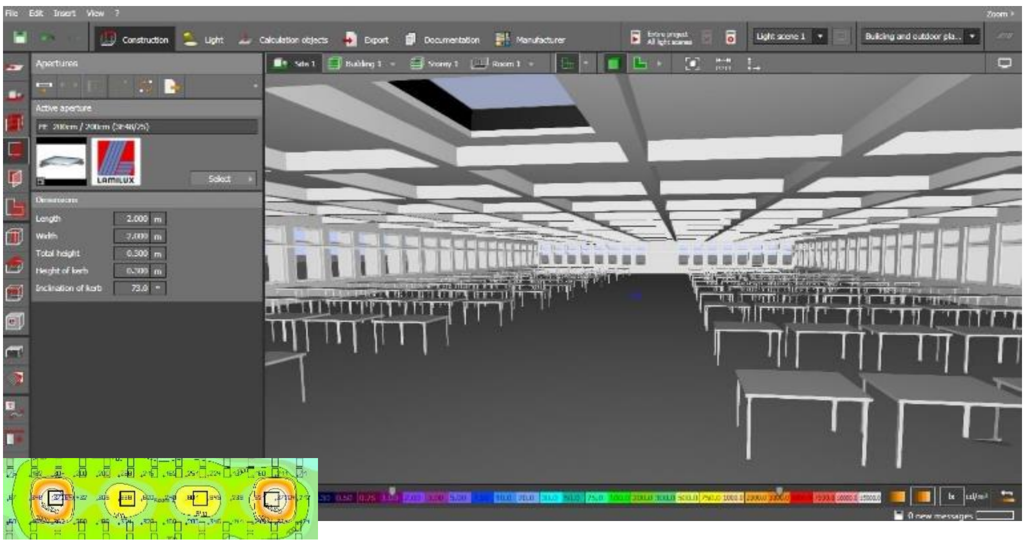

Fig. 11 Lighting distribution in the space after adding a light shelf and skylight using Dialux simulation program source: authors

So, from the above, the research proved that the studio could reach the required illumination using traditional and intelligent illumination Systems that depend on daylighting. Thus, reducing the lighting energy consumption and the building will be more sustainable.

6.3 Third retrofitting strategy: Integrating efficient artificial lighting with daylighting.

Another retrofitting strategy is integrating efficient artificial lighting with daylighting by using efficient LED luminaire. The luminaire is distributed to put many luminaires in the center of the space where the minimum illumination and reduce the number of lighting units near windows where the maximum natural illumination during the day as shown in Fig. 12.

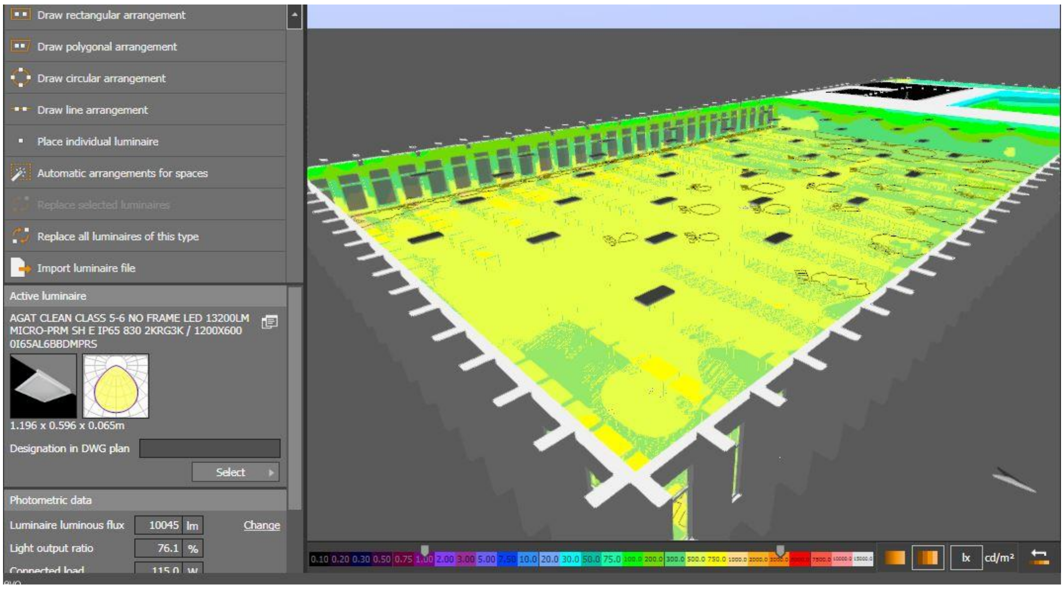

Fig. 12 Lighting distribution in the space after adding lighting units using Dialux simulation program source: authors

In this case, the light shelf enhanced the lighting distribution without glare, and the artificial light provided the middle of the space with target illumination. So, this strategy saves more energy than the artificial existing case and distributes the daylight uniformly without glare better than the base case as shown in Fig. 13.

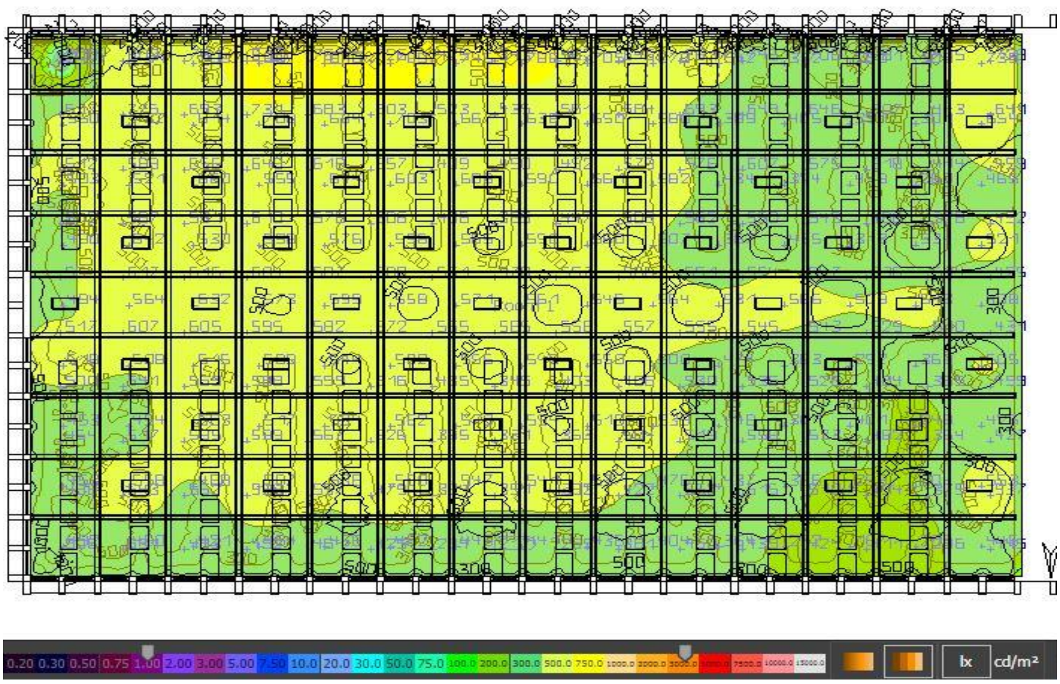

Fig.13 Light shelf +artificial lighting source: authors

7. Limitations

The following are instances of research limitations:

- The study focuses only on deep educational studios in Cairo .
- Sky light can be applied only for the upper floor but the lower floors can use light tube retrofitting strategy.
- Simulation-based approach: The study relies on a lighting simulation program (Dialux) to evaluate the daylighting strategies.

8. Conclusion

Daylighting is an important natural source that the building can depend on. It helps in improving human health and well-being. Enhancing Daylighting by using traditional illumination Systems like windows, atrium, courts, and skylight, and modern illumination Systems such as light shelves and solar tubes in the deep educational studios make the building more sustainable, healthy, and reduce building energy consumption.

Daylighting retrofitting strategies help the designer to enhance the dependence on daylighting in an existing building, thus decreasing the dependence on artificial lighting. The lighting simulation program helps the designer to optimize and find the best retrofitting strategy.

The research examines a lot of retrofitting strategies like using a horizontal and inclined light shelf with 15 degrees of inclination, utilizing a skylight, and integrating natural and artificial lighting.

The results show that the best strategy is using a light shelf that reduces glare beside windows and lets the daylight go into the deep parts of the space integrated with skylights that illuminate the central part of the space, the second strategy is integrating natural and artificial lighting. However, it consumes energy but less than the existing one as shown on Fig 14 the results of daylighting factor metric. Also, these strategies can be generalized in enhancing deep spaces daylighting distribution.

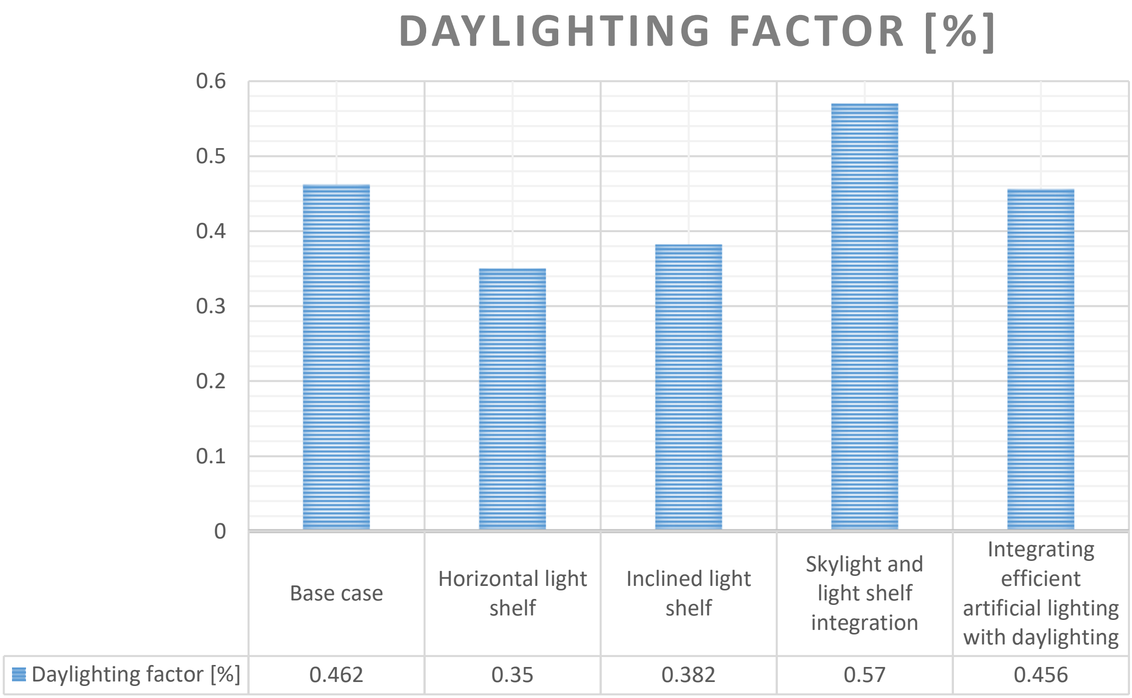

Fig.14 daylight factor (%) in the base case and retrofitting strategies source: authors

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