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Economic Feasibility of Energy Saving by Incorporating Daylight: A Case Study of College Building in Multan-Pakistan

N. Blouch[1], N. Akram[2], A. M. Malik[3], M. Rashid[4], F. A. Siddiqui[5]

[1]*Department of Building and Architectural Engineering, Bahauddin Zakariya University, Multan, Pakistan*
[2]*Department of Design and Interiors, The University of Faisalabad, Pakistan*
[3,4] *Department of Architecture, University of Management & Technology, Lahore, Pakistan*
[5]*Department of Mechanical Engineering, Bahauddin Zakariya University, Multan, Pakistan*

[3] ayesha.malik@umt.edu.pk

Abstract- Artificial lighting accounts for a substantial part of electrical energy consumption in any building. For a country like, Pakistan where the demand and supply gap regarding electrical energy is augmenting in the last few years, there is a dire need to design an appropriate lighting scenario that can help in reducing electrical energy consumption without compromising its thermal comfort. A case study building was selected to analyze the fundamentals of daylight performance and to demonstrate the basic daylighting strategies (ventilation & daylight) that could potentially reduce the need for artificial light. Heliodon was also used to investigate building physics related to the sun's path. This study investigates the daylight and thermal scenario of an educational building in Multan-Pakistan. The methodology into three stages: the first involved analyzing daylight and energy efficiency for the case study, the second involved identifying and implementing the best solutions without disrupting the building's existing architectural designs, and the third stage included a heat and daylight comparative analysis of both cases using the ECOTECT software. The results show the possibility of electrical energy savings up to 28% with not only improved natural lighting conditions of working areas but sun glare near South-faced windows was also improved to a great extent. The study proposes the principal strategies for improving building performance. These approaches assist architects in predicting optimal energy performance and daylight strategies by developing appropriate climatic design options and identifying the link between design demands and daylight efficiency metrics. All these considerations are expected to benefit the environment in the end.

Keywords- Daylight, Thermal Energy, ECOTECT, Heliodon, Energy Cost.

I. INTRODUCTION

From 1947, Pakistan tuned into a rapidly rising economy, and the 6th most crowded nation on the planet, just as the quickest urbanizing South Asian country [1]. Regardless of persistent populace development, arriving at 197 million, the annual Gross domestic product rate has changed [2]. In corresponding with its populace growth, Pakistan's energy utilization has continuously risen to a degree of 80.9 M toe in 2017 [3]. Despite lingering behind numerous South Asian nations, in respect of per capita consumption of energy, the overall rate of energy consumption is increasing. In the country, the gap between the growing energy demand and limited resources is intensifying [4]. According to the National Electric Power Regulatory Authority (NEPRA), the gap between the generation and demand of electricity is expected to keep on growing, despite the finish of ongoing energy projects (National Electric Power Regulatory Authority [5]. Moreover, the expense is calculated by 2.6% of Pakistan’s GDP of attaining consistent access to electricity [6]. Major electricity users in Pakistan are: agricultural, building, street lighting, bulk supplies, etc [7]. The building sector is responsible for the highest amount of energy consumption compared to energy use in different sectors[8]. Overall, the conservation of energy in the building by energy efficiency has obtained key importance. In a building, the main four features of energy efficiency contain; zero passive energy building design, low energy materials usage, energy-efficient gadgets usage, and lastly, renewable energy tools and technologies integration for various equipment [9]. In the building sector, mostly the energy is used for operational purposes; for the building servicing and maintenance throughout its service life, and as an embodied energy; such as the total required amount of energy for the production of buildings using equipment, and different materials [10]. Especially, in educational buildings where space directly influences learners and teachers learning and working capacities, it requires special attention for the sustainable building's development to provide the occupant’s visual and thermal comfort while minimizing the energy consumption[11]. Hence, using the least possible energy academic building should be planned in such a way that special focus is placed on the student and teacher performance.

This study uses a multi-objective approach. This paper aims to investigate the current daylighting conditions in a purpose-built private educational building located in the desert climate of Multan-Pakistan. In addition, the goal was to elaborate the connection of daylighting and thermal comfort conditions, as per previous literature and the simulation results the modifications were made in the building envelope to optimize the daylighting while considering the thermal comfort of the occupants. The study also aims to correlate daylighting with thermal comfort in terms of electrical energy cost savings. Furthermore, this research intends to investigate the effectiveness of flexible building design elements in minimizing the energy consumption of existing educational building elements.

The energy utilized during the service of structures includes heating, air conditioning, water heater, lightings, cooking, security, and operating the appliances. Whereas, lighting is one of the major electricity consumers. All around the building sector accounts for the world's electricity consumption of about 40% [12] of which lighting utilized nearly 19% [13] and is perhaps the greatest reason for energy-related ecological issues. Therefore, this study is an effort to assess the economic feasibility to reduce the electrical energy demand of buildings by incorporating daylighting through slight modification in the building façade.

II. Literature Review

To harmonize human activities with the sunlight at the peak periods of energy consumption [14] efforts are made by different researchers to incorporate daylight techniques to introduce sustainable building designs to minimize energy issues [15-19]. Maria Beatriz Piderit Moreno and Constanza Yanez Labarca investigated the daylit classrooms located in three different typographical cities of Chile, by apply four different strategies [20]. Researchers carried out a comparative analysis of daylighting performance between the case study and other climate-based proposed daylight models by using Radiance software. It was shown that the provision of upper blinds offers an ideal condition to expect energy savings that almost does not require complementary artificial lighting and the best results were obtained with the light shelf and Southern skylight. But in the winter season, necessary to use artificial light [20].

Buildings heating and lighting are the main energy consumers, where heating accounts for 55 -60% and lighting for 27 - 40% [21]. Buildings have been changed to decrease energy consumption and are designed to harness Sun energy to optimize indoor visual and thermal conditions [22]. Several studies have been conducted to identify the electric light effect on thermal perceptions, no study exists on the effect of daylight. Giorgia Chinazzo investigated the first-time daylight relationship with the thermal comfort perception by presenting the controlled experimental analysis on the daylight quantity effect on human thermal responses. The findings prove that daylight should be considered as a key factor in thermal comfort paradigms and all investigations of thermal comfort, in addition that the conditions of daylighting and thermal comfort should be adjusted through the usage and building design strategies to assure its inhabitants' thermal comfort structures [23].

Patricia Plympton discussed the evidence regarding daylighting and student performance [24]. Four newly constructed case studies of schools were selected that implemented cost-effective daylight strategies (e.g. orienting the building to maximize the daylighting potential and undesired heat gain, provision of louvers controlled from an electronic switch, triple-glazed glass, and high-efficiency fluorescent lights) into the buildings. Results showed no significant construction cost increased over conventionally designed school but notable long-term cost-saving, as well as increased performance (as measured by test scores) and general health and well-being students, were observed. Different research methodologies were adopted by Phani kumar and Raju, various alternative energy sources like solar, wind and geothermal energies proved to be better in creating an energy-efficient built environment; along with these effective criteria for daylight, utilization plays a crucial role in creating energy-efficient buildings. Researchers have also proven the best efficiency of daylighting and energy-saving potential in an institutional building during the time of the day to reach the optimum performance of daylight by using Autodesk Ecotect [25]. According to one more research study conducted in South-Western Nigeria, the sunlight in higher educational buildings have great potential for energy saving to advertise energy conservation. The researchers conducted two hundred open-ended surveys on the institutional building users and analyzed by mean score index descriptive statistics and. Research results showed that energy wastage is common with lighting usage poor controls for both lighting and other equipment. Building operations related to lighting also exert substantial effects on energy wastages. The major aspect influencing energy consumption is due to poorly designed higher educational institutional buildings. Moreover, results revealed that changes in passive structure designs are critical to the cut the energy consumption and it can spare the cost [26].

Furthermore, some researchers have also examined the policy effects on natural light saving through the difference-in-differences approach and calculated the energy cost savings as a yearly electricity consumption rate. The research findings suggest that sunlight saving can stabilize the curve of electricity demand [27]. Researchers confirmed that daylighting must be promoted in buildings for lighting purposes to reduce energy consumption. Yet at the same time, daylight harvesting practices are complicated and have a capacity in energy savings equal to 40%-60% when designed appropriately. Conversely, they can become useless even increasing the total energy use due to faulty installation [28]. Hence, the inclusion of daylight can be one of the most demanding and significant factors to address the electric energy demand-supply gap in the building sector.

Hence, for minimizing the energy consumption in the building sector especially in academic structures daylighting can be an effective way while transforming the existing flexible architecture elements of buildings (e.g. sunshades, canopies, etc.). Daylighting has a clear relation with the thermal perception of building occupants and can affect the students' and teachers' working capacities negatively if these are not addressed properly. The case study of an educational building is a purpose-built academic structure where existing lighting conditions are poor that are affecting the users' visual comfort. As the building is located in a desert climate where the provision of daylighting punctures can be a threat to thermal comfort and it will increase the building energy consumption. The computer simulations method "Autodesk ECOTECT" has been adopted to evaluate the existing building lighting conditions. Later on, certain modifications have been made in the building envelope and existing flexible architecture elements, then modified daylighting conditions and indoor thermal comfort have been analyzed.

III. Scope of Research

Currently, Pakistan is facing severe energy crises [29]. So, this research is an ongoing effort to minimize energy consumption in educational buildings without spending much. Lighting cost in educational institutes has become a major concern to communities which continuously keeps on increasing. Natural Daylight provides the opportunity to greatly reduce the negative impacts created by the overdependence on electric lighting sources [30]. The scope of this paper is to examine some basic opportunities, by improving the natural lighting system of different classrooms of a case study building and is to create a comfortable environment. Besides brightness distribution and potential electricity cost savings are the major considerations. The climate in Multan is called a desert climate. There is virtually no rainfall during the year in Multan. This location is classified as BWh by Köppen and Geiger. The average annual temperature is 25.6 °C in Multan. In a year, the average rainfall is 175 mm [31].

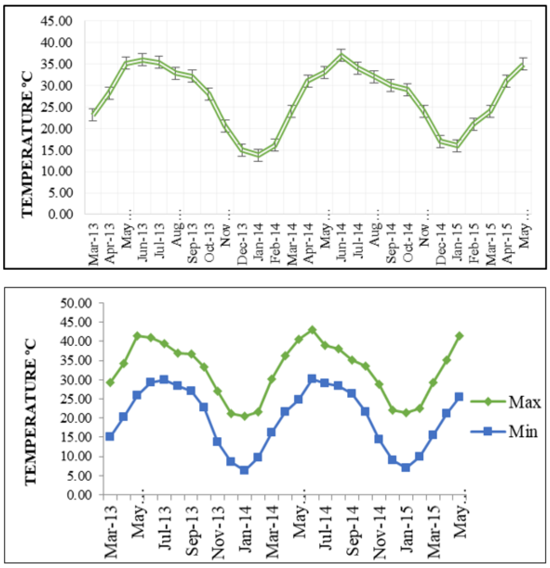


Figure 1. Average maximum and minimum range of temperature of Multan, Pakistan.

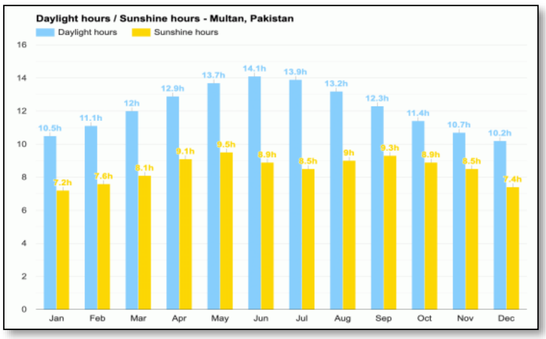


Figure 2. Daylight and Sunshine hours per month of Multan, Pakistan

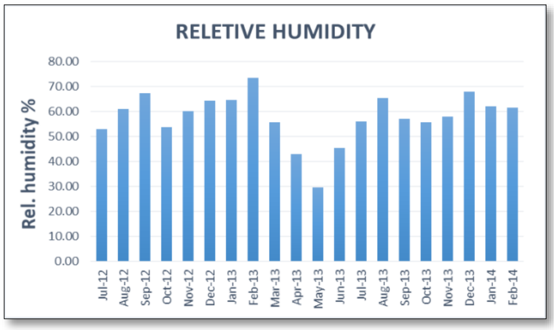


Figure 3. Relative Humidity per month of Multan, Pakistan

The driest month is October. There is 2 mm of precipitation in October. Most of the precipitation here falls in July, averaging 50 mm. With an average of 35.5 °C, June is the warmest month. January is the coldest month, with temperatures averaging 13.2 °C. The precipitation varies 48 mm between the driest month and the wettest month. Throughout the year, temperatures vary by 22.3 °C.

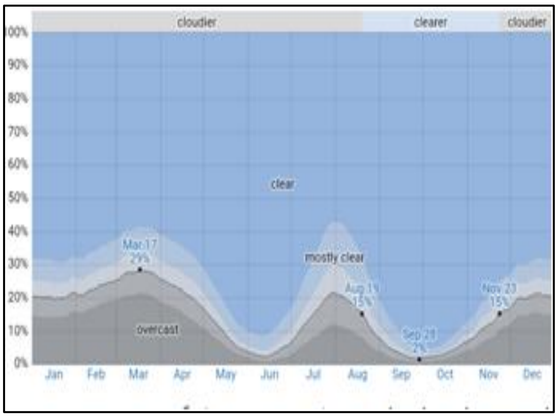


Figure 4. Sky Conditions of Multan, Pakistan
Source Figure 1-4: [31]

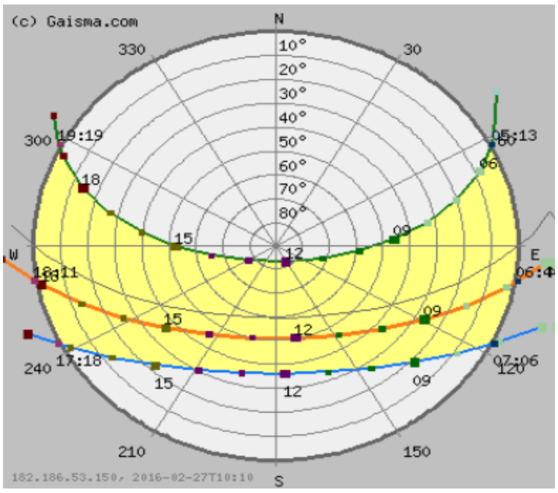


Figure 5. Sun path diagram of Multan, Pakistan
(Source: Multan weather data file)

Building Description

The building is a newly constructed double-story private college building in the city of Multan, which falls within the hot climatic zone. The building is a rectangular-shaped and concrete structure without any external insulation. The main facade of the building is oriented towards the East and has large openings. Whereas, the South and North facades allow very little daylight to enter inside. The main classrooms are exactly facing South while some laboratories having North façade and window openings are wooden framed, with single glazing and associated with a very narrow 3 ft. wide void through a corridor. This narrow opening to the sky may contribute little to no effect in the indoor environment particularly the provision of daylight into the rooms.

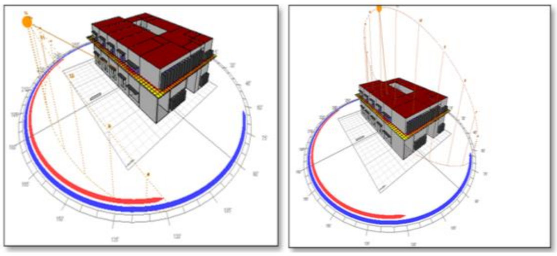


Figure 6. The orientation of Educational Building (case study) during winter and summer Winter & Summer Sun Path. (Source: Ecotect output)

IV. METHODOLOGY

The country is facing escalating trends in urbanization which is the main cause of an increasing gap between energy demand and supply [32]. To overcome this energy gap power is shut down intermittently for 6–8 h in urban centers as a last alternative. To encourage energy-saving strategies; daylight provision at different zones of the case study was measured by calculating the illuminance level (lux). To measure the illuminance level, a climate-based daylight metric was performed by using physical and software simulations [33 - 34]. As Multan is located in a very hot climate Nicol, Raja, Allaudin, & Jamy consequently observed the negative impact (if any) of natural Daylight on the HVAC system, monthly heating and cooling loads were also calculated [35]. The existing artificial lighting pattern was also observed (which was general lighting with fluorescent tubes) to calculate the monthly electricity bill.

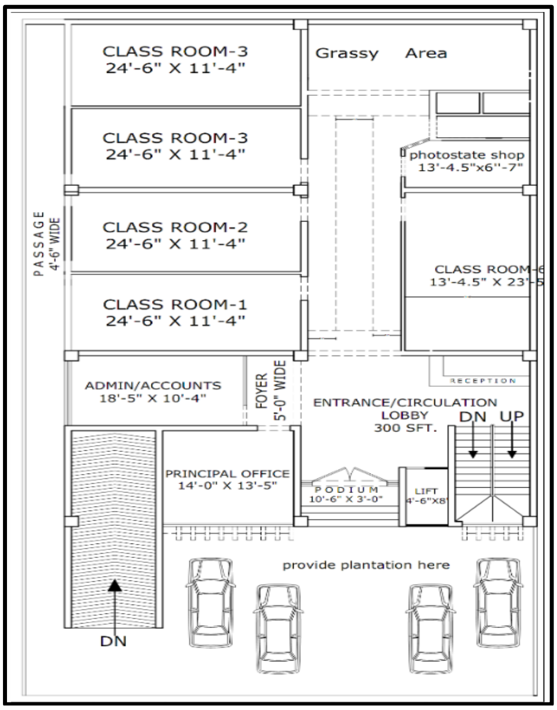


Figure 7. Case Study- Educational Building
Ground Floor Plan

After evaluating the existing building energy consumption conditions, certain modifications in the original building based on previous shreds of research evidence for energy and cost savings were implemented. After slight modification in building design, it was again analyzed based on daylighting and thermal conditions. Nomenclature and minimum lighting level for different areas of the educational building determined by European Standard EN 12464-1 [36] are given in the table below.

Table 1.Nomenclature and European lighting level of an educational building

Areas	Acronyms	Standards (European)
Staircase	SC	200
Lift	LIF	100
Principle off.	PO.	500
Admin off.	ADO	500
Ent. Lobby	EL	300-500
Classroom	CR-1	300-500
Classroom	CR-2	300-500
Classroom	CR-3	300-500
Classroom	CR-4	300-500
washroom	WR	100-150
Computer lab	CL-1	300
Computer lab	CL-2	300

4.1: Proposed Building Modifications

After determining the sun path, orientation, and architectural design of the existing case study with the help of Heliodon and previous literature to determine the lighting conditions, the building was critically analyzed for the daylight to verify the energy-saving potential. Direct solar heat gain was also determined. The overall picture of the building was found very disappointing concerning energy saving. Dead Southside of the case study building increases the use of artificial light which does not allow natural light to enter. As this is an educational building and used in day timing so the integration of daylighting can greatly reduce the building electricity load. Certain modifications can bring dramatic changes in electricity consumption .1) Introduction of small horizontal strip windows and exterior light shelves with shades of the lower windows at the South façade. 2) Provision of Indoor Venetian blinds to control the amount of daylight during extreme weather.3) Introduction of moveable vertical louvers at the front façade (East facing). 4) Provision of Ivy plant bail on the West and East façade for heat control. 5) Application of white color paint instead of dark grey marble in the internal courtyard to reflect the sunlight to the first floor. 6) Installations of LED (light-emitting diodes) lights instead of fluorescent tube lights to save electricity.

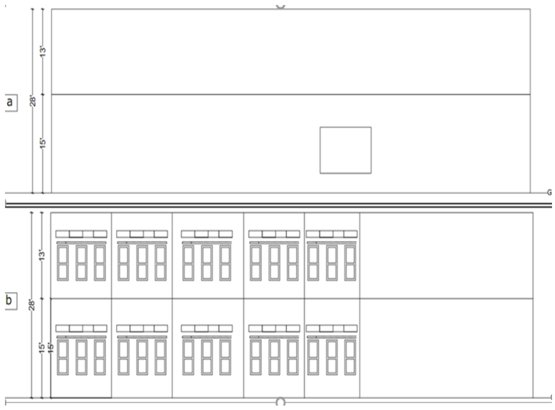


Figure 7. South Elevation of Case study (a) proposed modified building (b)

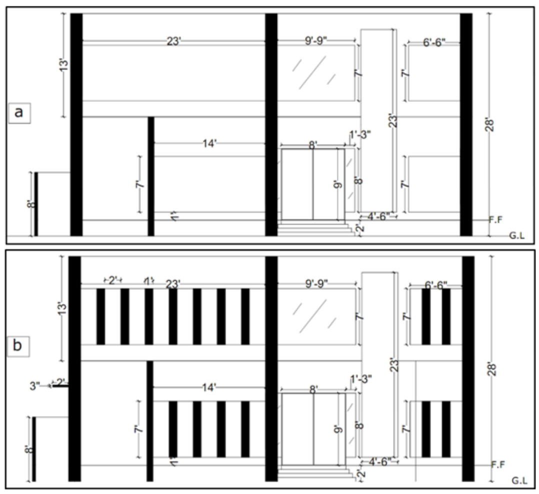


Figure 8. East Elevation of case study (a) proposed modified building (b)

V. Analysis and Simulation

The case study educational building was Analysis adopting two different methods.

5.1. Physical Analysis of Case Study building Daylight through Heliodon

A heliodon's version based on Norbert Lechner's design was constructed at the latitude of Multan (30.1575° N, 71.5249° E) to physically simulate the building physics to the sun path across the sky (see Figure 10).

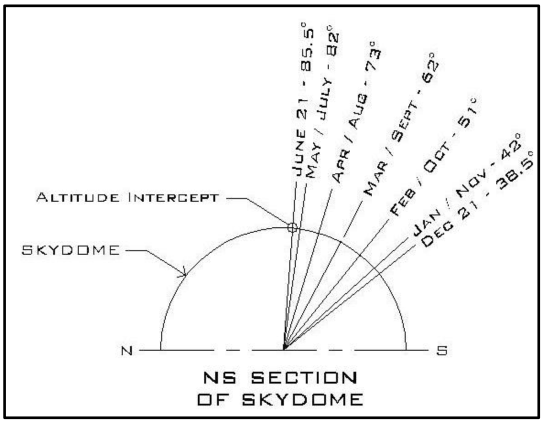


Figure 9. Altitude angles at noon at Multan's latitude (21st of each month of the year)

Heliodon analysis was performed to observed light entering the pattern at the East and South facade at different solstice for the Northern hemisphere. It is clear from the above Figure that the East facade gets sun every day of the overheated period but June 21st receives the strongest and most direct sun. Daylight patterns at the exterior of the South façade are shown in the Figure above. It is evident from the above analysis that the sun shines directly on the South façade during the hot months e.g. from May to September but due to large altitude angles windows on South can easily be shaded with overhangs and the size of shades determined with the help of Heliodon. Consequently, much strong and direct sunshine was observed on December 21st at the South façade which is also helpful in reducing winter heating load. From the physical analysis results, it is clear that the building located in the Multan usually experienced more sunshine in the East and West windows during the hot months. The East and West facades receive the strongest and most direct sun but heating effect. At the North, façade sun is relatively weak because its altitude is low and it hits the windows at an angle from East or West.

Figure 10. Heliodon analysis to check daylight scheme of building

However South façade entertains the sun shines in cool months and the high angled sun can easily be controlled through horizontal shading devices during hot months.

5.2. Software Simulation

After going through various methods and software, Autodesk ECOTECT was selected for the simulation of this research. The ECOTECT is a highly visual architectural design and analysis tool that links a comprehensive 3D modeler with a wide range of performance analysis functions covering thermal, energy, daylighting, shading, acoustics, and cost aspects. Due to availability and quite similar weather data and coordinates, Lahore's weather file used the coordinates of Multan city 30.1575° N, 71.5249° E. The analysis was conducted at three times of the day and three periods of the year, at two different heights of every floor of the building. Observations were collected in the form of a daylight factor for each area of the case study at an equal interval. Overcast sky conditions have been considered to cater to the worst-case scenario for daylighting. Daylighting factor is further converted into the lux levels to determine the average illuminance for each area. Building climate data, plans, sections, elevations, and envelope design elements such as walls, windows, roofs, etc., along with the materials and construction details were used as input data for Autodesk Ecotect software for performing lighting and thermal energy simulations. The complete optical characteristics of the building are shown in table.

Table 2.Optical characteristics of case study building

Start point conditions	0.80 m
Height of desk	4 ft.
Height of whiteboard	5 ft.
Widow-to-wall ratio (East)	75 %
Widow-to-wall ratio (South)	10 %
Window-to-floor	40%
Sill height	3ft
Glazing transparency	Clear
Floor reflectance	20%
Ceiling reflectance	70%
Walls reflection coefficient (East)//u value of walls Walls reflection coefficient (South) /u value of walls	3.4 0.5
Furniture reflection coefficient	0.35

VI. Results and Discussion

6.1 Comparative Daylight Analysis with and without Modifications

The comparative analysis of the case study and proposed modified building were conducted with the same structural data provided by the architect of the building for the dynamic simulation process. The graphical representation of comparative analysis of a case study and proposed modified building of all areas facing different orientations and standard illuminance required for the particular area are shown in Figure 12 & 13.The plan of the building (both cases) with luminaires or light distribution patterns at different heights and times are shown in Figure 14.

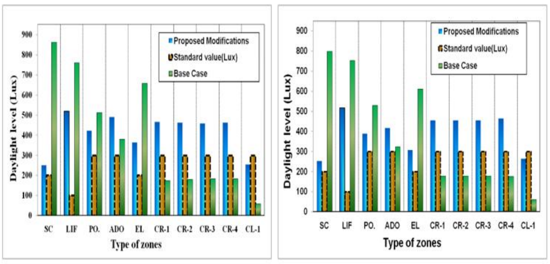


Figure 11. Comparison of daylight level (lux) of various areas at a height of 3’ and 6’ respectively (Ground floor).

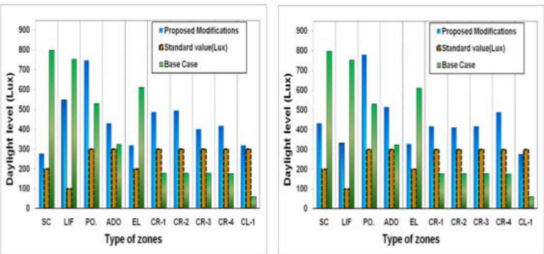
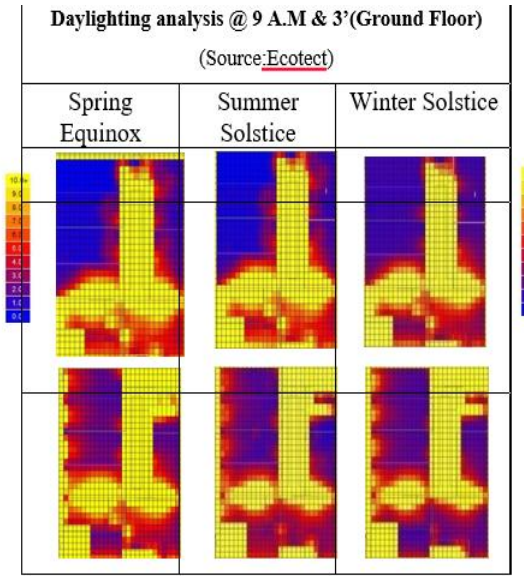


Figure 12. Comparison of daylight level (lux) of various areas at a height of 15’ and 18’ (First floor)



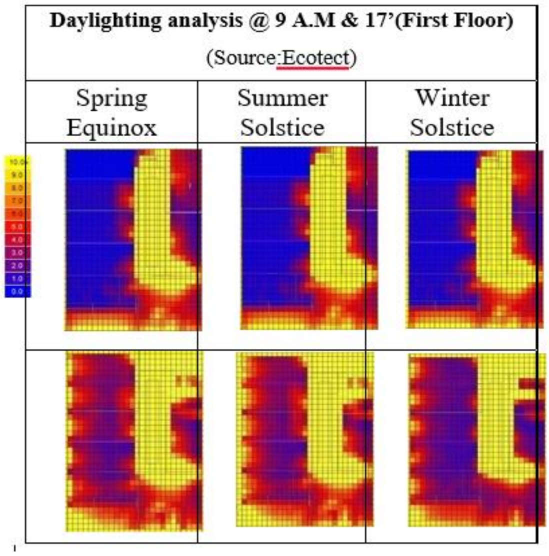


Figure 13. Daylight analysis simulations showing %DF (the amount of light falling at different points over the measurement grid for different months of the year at noon [source: Ecotect]

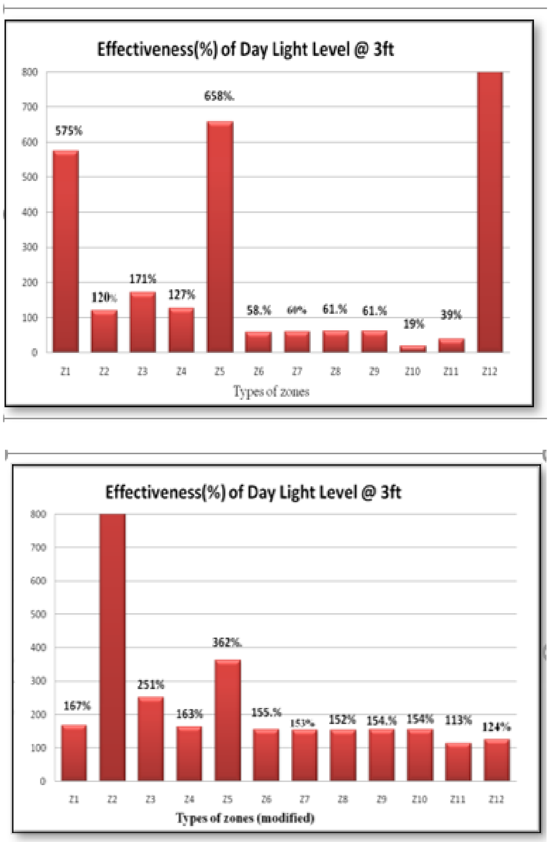


Figure 14. Effectiveness of daylighting in the Case study and propose building w.r.t standard Value at 3’

6.1.1. Light Distribution Pattern at East, West, and North Façade

From the results obtained, it can be concluded that East facing areas on the ground floor (SC, LIF, PO, and EL) were experiencing too much light in case study building at all heights (e.g. 3'and 5').

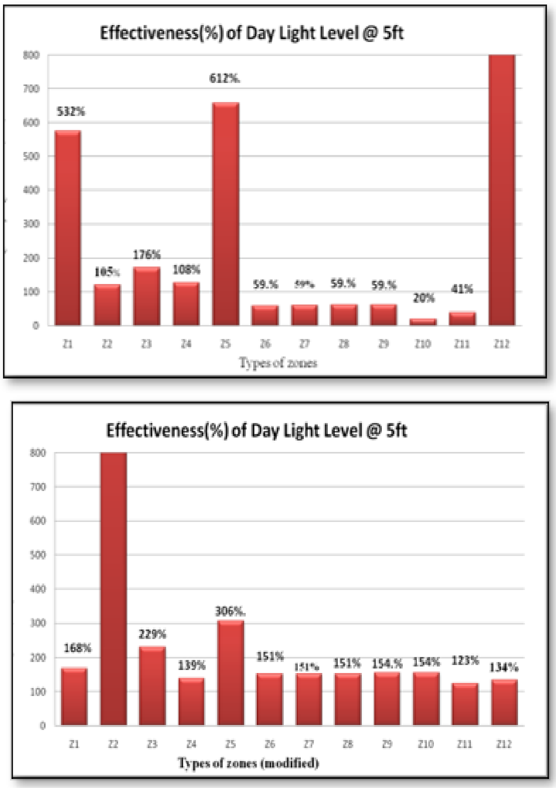


Figure 15. Effectiveness of daylighting in the Case study and propose building w.r.t standard Value at 5'

The minimum requirement of the daylight level (lux) for the staircase (SC) is 75-100 lux [37] but the average recorded value at different solstice was 869 lux. Since SC is orientated to the East and supposedly receives the most sun in the mid-afternoon. For a city like Multan where summer cooling is the major objective East sun dangerously affects the cooling load [38]. To improve the daylight illumination without changing the original orientation of the SC area, optical systems of moveable vertical louvers are adapted as alternative design strategies for redirecting daylight to areas. The success of this system can be seen in graphical representation as the lux value considerably lowers approximately equal to the standard value (Figure 15 & 16).

Conversely, the documented daylight level was satisfactory to meet the requirements of the European standard [36]. The same results were also discovered in all other areas of the case study building facing the East façade. This is mainly because there are no overhangs over the windows to avoid direct contact with the sun. Likewise, zone SC and all other areas of the case study facing the East side are treated with the same shading treatment (expect lift) of vertical louvers in proposed modifications and similar trends were obtained e.g. in the case of zone PO and EL the recorded daylight value (lux) for case study 513 and 658 lux respectively which after modification improved to the value of 421 and 360 lux in that order. Northside remains dead bordering on the original building and has no windows. It was mainly attributable to the adjacent high-rise structure. Comparative adequacy of daylight in the East-facing front lobby that represents the daylight scenario of both cases is shown in Figure 17.

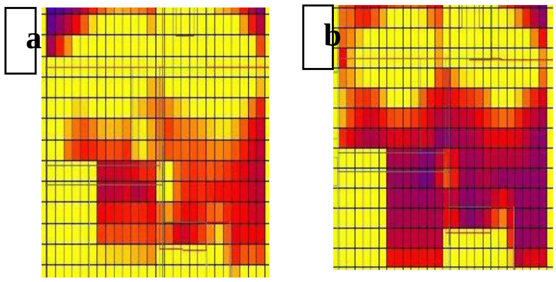


Figure 16. The daylight scenario of the East-facing lobby of the case study and the modified building is shown in Figure a & b respectively.

6.1.2. South Façade

The entire classrooms except for the computer lab (CL-1) were facing the South façade. Comparative adequacy of daylight in all classrooms that represents the daylight scenario of both cases is shown in Figure 18. All windows of case study classrooms are provided in a North-facing covered corridor which does not even fulfill the minimum requirement of EN 12464-1 for casual reading. It was very challenging to design a classroom's (South-facing) windows in this hot climate with the best performance of daylight to maintain thermal comfort with minimum consumption of artificial energy [39]. Multan is located in a hot arid region where climatic constraints are very important, e.g. summer cooling is of prime importance [40]. To overcome these difficulties horizontal slit windows with light shelves were provided for high-quality daylight as well as to control the summer sun [41]. The results of the modified plan with the light shelf and horizontal slit windows are good and from the obtained results we can assure energy savings that almost does not require complementary artificial lighting during sunlight hours. But it might be possible to require artificial light during the winter, in the period with the greatest demand. The illuminance on the work surface would be compared with the CIBSE [36][42]. The average recorded value of illumination for different classrooms is 300~500 lux [43]. This will also positively affect the student's health [44]. This phenomenon is well explained in research, it is reported that Seasonal Affective Disorder (SAD) is a relatively common disease that is directly related to the amount of daylight in our buildings or at workplaces [45]. Reports also illustrated that almost 9.7% of the world's population may suffer from SAD and the symptoms of this disease can be reduced through the effective value of daylight especially in winters [46] [47]. Light therapy can also be used to treat some other non-seasonal depression-related illnesses e.g., premenstrual, bulimia, etc [48]. The lighting system will also be downsized, which results in reduced electricity consumption as well as monthly electricity bill. The illumination values of all classrooms' areas of the modified plan at different heights are shown in Figure 18. Venetians and curtains are also provided as indoor shading devices to reduce the sun entering when there is too much sun.

To make results more clear it was necessary to compare the effects of glare in a classroom for both cases. Illuminance value varied from inadequate to excessive. According to European standards [49]. glare is usually produced owing to excessive artificial lighting and also from poor control of daylight. For all the classrooms of the case study, the seating position near the window was considered comparatively comfortable for visual performance as shown in Figure below. It was observed that light diminishes rapidly with increasing distance from the window (Figure 19) which is one of the main causes of glare. To control the sun and to downsize the glare effect, all South-facing rooms are designed with horizontal slit windows (3 small size windows) instead of providing one large window. Light shelve was also provided over the windows. Horizontal shading elements are also very helpful for South-facing windows in evading direct contact of sun and room. As a result, it was observed that in the case of modified design light distribution (throughout the room) was quite better due to the provision of Light shelves and more than one window. Light shelves allow the sun to penetrate deeper into space which is the main reason for better light distribution [50]. The amount of light generally depends on the depth and volume of space through which it will travel [51].

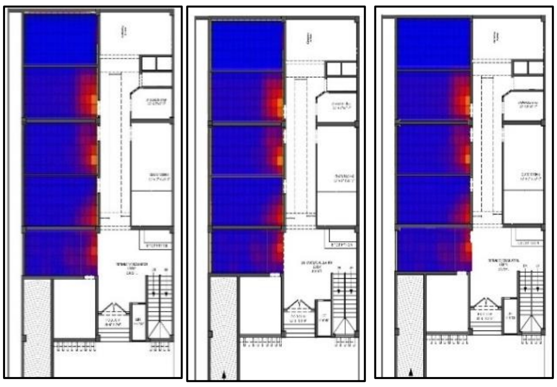


Figure 17. Daylight distribution pattern in South-facing classrooms at a height of 6ft in a noon of case study building (Summer, Winter, and Equinox Solstice respectively).

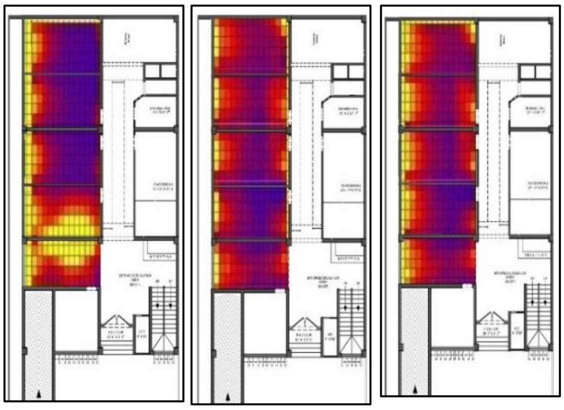


Figure 18. Daylight distribution pattern in South-facing classrooms at a height of 6ft and noon in a modified building at different solstices (summer, winter, and Equinox respectively).

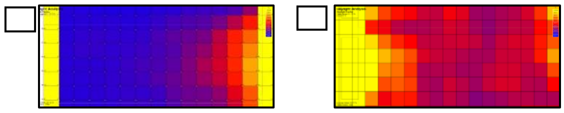


Figure 19. Comparative Daylight diminishing pattern of CR-2 case study a) and modified b).

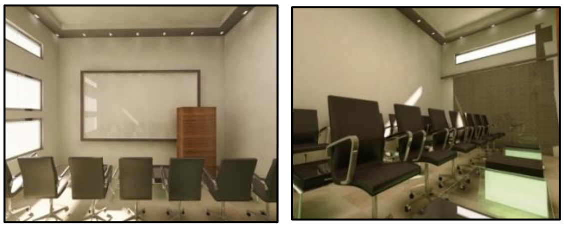


Figure 20. Rendered images- Daylight pattern of CR-2 modified building with open and closed internal shading devices.

It is clear from the above Figure 21, that the geometry of the room was carefully designed in such a way to provide a high level of natural light while avoiding the phenomenon of glare. The design of horizontal windows on the South façade ensured a good quality daylighting distribution in the classroom with an average daylighting factor in the range of 3.5 to 5.5 %.

VII. Thermal Analysis and Simulations

In hot climates like Multan daylight penetration or sunlight certainly allows unwanted heat penetration into the building [52-53]. So, it was very important to acknowledge the risk associated with bringing in solar radiation, especially in terms of thermal discomfort and excessive cooling loads [54-55]. Openings of the building play a crucial role to address the harshness of the outdoor climatic effect on indoor temperature [56]. If the openings of the building are properly designed, then instead of increasing it will decrease the energy consumption and reliance on mechanical ventilation [57-58]. The openings (windows and doors) if carefully handled will contribute to illuminating the interior with daylight but also helps to interconnect the indoors with the outdoor and allows natural ventilation [59-60], and plays an important role for thermal relief to the occupants [42][61]. Therefore, it is necessary. The research further investigates the possible relations between the use of openings and the thermal comfort of occupant's educational buildings. The Ecotect software can calculate the monthly energy consumption pattern of the building. Both the buildings were critically analyzed for their vulnerability to direct solar heat. The comparative analysis results are discussed under these subsections.

7.1 Monthly heating and cooling loads before and after modification

Analysis results revealed that the maximum cooling was requisite during June. Energy by an amount of 136472 W was required to cool the conditioned areas of the case study building, which was reduced to 132190 W after proposed modifications. Both values were taken at 11o clock on 11th June. From the results, it is revealed that providing proper windows orientation and controlled window size, and position and size of overhang especially for the South-side also decreases the cooling load. From the simulation results, it was found that maximum heating was required in January. In the case of heating load, the improved results were achieved for the proposed modification and the energy reduces by an amount of 487W. The energy required to heat the case study was 2126 Wand for the proposed modified building it decreases to the value of 1639W. Since most of the classrooms are South facing and in winter period the sun is inclined towards the South with a long-time subsequent incident solar radiation creek through the window to the facility. Contrarily the building has a dead North-side where solar radiation incident on the North window is minimum compared to other orientations. It is determined that the classrooms having windows locating at South does not need a heating process for the hot climate conditions like Multan. The monthly cooling and heating load results of the case study and proposed modifications are shown in Figure 22.

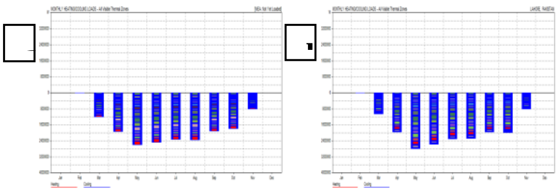


Figure 21. Monthly heating and cooling loads of baseline building (a) and proposed modifications (b).

It was observed that daylighting improvements also illustrate a considerable reduction in cumulative annual energy use for lighting, and cooling energy as well. So, it is clear from the above facts that daylight does not have any negative effects on the energy regime rather improved it by reducing artificial lighting consumption.

7.2 Hourly heat gains before and after Modifications

As Northern Hemisphere generally receives the strongest and direct sun from the East and West façade which transferred heat into indoor spaces, increasing the internal cooling load during the summer season[62]. After shading the East façade of the proposed modified design with vertical louvers, the direct sun enters the room with little hurdles; consequently, a reduction in the hourly heat gains was noticed. During the 16th hour (i.e., from 3: 00 pm to 4: 00 pm), due to the hourly heat gain case study model experienced a maximum load of 59922Wh. Out of this total heat gain, the HVAC system of the building was bearing 29961Wh (almost 50% of the total heat gains) as shown in Figure 23.

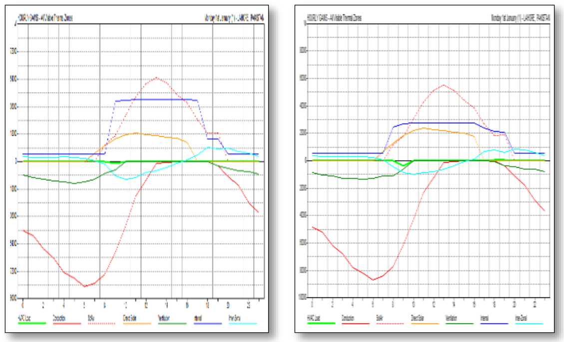


Figure 22. Hourly Gains before & after Modifications for June 11th respectively

Proposed modifications in the case study demonstrate better results. The peak value observed at the 16^{th} hour (e.g. 2.0 pm to 3.0 pm) was 5843 Wh, which contributes to HVAC systems. However overall results show much improvement which proves that sun rays were blocked with the proper shading device. It was also observed that during the 12^{th} hour the solar radiation hits the building from the roof or walls even stronger because in East orientation (window to wall ratio 65%) the sun remains all day long and especially when it is most intense.

7.3 Ventilation gain

Natural ventilation is an effective passive strategy to optimize and measure the airflow [63-64]. It can be achieved by clearing the indoor air, lowering the temperature, and expelling the humidity[65]. The amount of ventilated air, the airflow over and inside the room through the window are mainly affected by the wind speed and the ambient and inside air temperatures. It is observed from compared results of both cases that natural ventilation shows much improvement in the modified case due to cross ventilation. The introduction of the window at the opposite side of doors enhances the mechanism of cross ventilation which improves the indoor thermal comfort and provides fresh air without energy consumption. Therefore, natural ventilation should be paid enough attention to cut the energy. The ventilation gain pattern of both cases is shown in Figure 24.

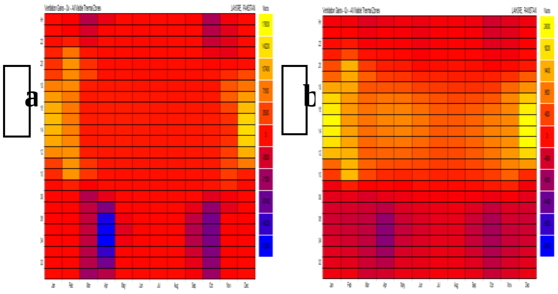


Figure 23. Ventilation gain Case study (a) ventilation gain of modified building b)

The region of the case study building (Pakistan) has the highest electricity rates due to the energy crises therefore the daylight improvement strategy also provides substantial cost benefits over the case study [42] e.g., for 201–300 units the rate per is Rs. 10.20 per unit and the rate per unit from 301–700 units is Rs. 15.45 Per unit and for the units Above 700, the rate is Rs. 17.33 per unit. Several factors affect the transformation in result profiles between energy use and energy cost. For this purpose, the number and type of appliances and equipment used in the case study comparative analysis the building were critically investigated. Compact Fluorescent Tube lights (60 W) were used in the existing building. But in proposed modifications LEDs (Light Emitting Diodes) were used instead of CFLs (Compact Fluorescent tube lights) an evident in the use of energy-efficient lighting; however, peak loads are also affected by such design decisions and the

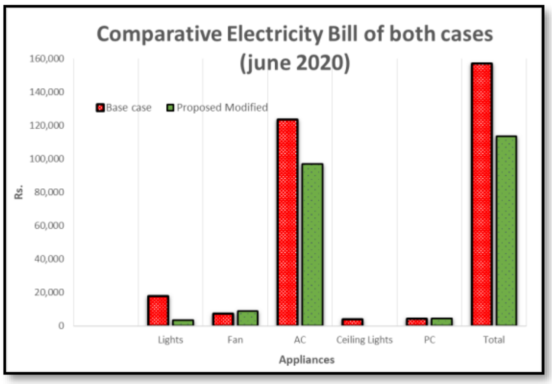


Figure 24. Comparative electricity bill current and modified cases for June

monthly winter and summer temperatures give a good indication on the air conditioning power consumption and the level of comfort inside the building. Such simulations also predict ample energy savings when considering gross numbers of appliances; South-facing facades if properly design have higher DAR and therefore less energy is required for lighting the space. For 30% WWR, annual electricity demand for lighting is already reduced by 77% (from 1800 MJ to 413 MJ) compared to passive lighting control and practically it is not further reduced for larger window areas (Khalid & Sunikka-Blank, 2017).

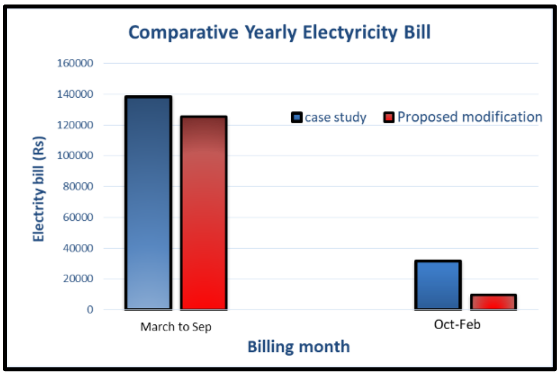


Figure 26. The comparative yearly electricity bill for before and after modification cases

VIII. Conclusion

This research explored how daylight contributes to the overall energy scheme of the building without conflicting with the energy system of the building. With the help of an accurate survey of the geometric, technological, and illuminance characteristics of the case study building, a validated daylight model in ECOTECT was built and climate-based daylight analysis under variable sky conditions was performed. The initial stages of the annual sun path of Multan city were also measured with the help of Heliodon. Useful Daylight Illuminance (UDI) and the Daylight Factor (DF) were used as the main tools to identify the problems of different areas of sample buildings, especially in the classroom. After finding the problems in the existing design a few modifications were proposed in windows orientations and shading devices the analysis was again made by using the same illuminance characteristics and geometry. It was found that these basic window designing techniques in any building especially building used in day time have many constructive functions and economic savings. Even for hotter areas, the economic and energy benefits of daylighting are much higher than the penalty as the gains can easily be controlled if daylighting issues are easy to manage in new buildings through an accurate design phase. Along with heat control, the major problem in a building observed was poor management of windows' sizes and shades according to orientation as excessive illuminance was observed in the areas facing the East facade which also contribute to heat gain. The scenario was different for South-facing rooms as the illuminance value goes on decreasing when moving away from the window. In the proposed modified model South façade was treated with horizontal slit windows and ventilators to reduce the potential glare risks for students sitting near the windows without negatively affecting the illuminance levels in the remaining areas and a more even distribution of daylight inside the classroom was observed. The proposed interventions for the East facade were just the provision of lovers and shades on windows and great improvement of natural light and energy savings conditions inside college buildings were recorded. This research addresses a clear evaluation of the benefits of daylighting design in a college building. It indicates that overlooking basic sustainable factors at the design level can abridge the high operating cost of the project, especially for the developing countries.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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