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Relationship Between Daylighting Design and Artificial Lighting Energy Savings in Office Buildings

[1]Umer Mahboob Malik
[2]Sana Younas
[*3]Rimsha Imran
[4]Zulfiqar Ali Tariq
[1]Assistant Professor, School of Architecture Design & Urbanism (SADU), IAC Lahore Pakistan
[2]Academics, School of University Studies, Keyano College, Alberta Canada
[*3]Lecturer, Institute of Design & Visual Arts LCWU Lahore Pakistan
[4]Principal Architect, NESPAK Lahore Pakistan
[1]umer.mahboob@iac.edu.pk, [2]sana.younas105@keyanomail.ca, [*3]rimsha.imran@lcwu.edu.pk, [4]humaira.kanwal@superior.edu.pk, [5]Zulfiqar.ali@nespak.com.pk

Abstract

This paper examines the quantitative design correlation of day lighting design strategies and artificial lighting energy savings in offices. As the focus on energy efficiency and the well-being of occupants has increased, the optimization of the use of natural daylight has become a major concern in sustainable architectural design. The study targets urban South Asian settings of office buildings, which require high-energy levels and climatic conditions that compound the necessity of passive lighting systems. The study follows a sample of ten office buildings with different types of design features of daylighting such as window to wall ratios, type of glazing, and spatial orientation using the lux meters and energy data loggers to track the daylight and artificial lighting consumption in a period of four weeks. A statistical analysis, which is regression based, is done to establish the degree of association between the daylight availability and reductions in electric lighting usage. Results show considerable negative dependence between daylight penetration and artificial lighting load whereby properly designed daylighting systems would achieve energy savings up to 35 per cent at the peak hours of daylight. Also, spatial orientation and window design have been observed to be significant variables that have an impact on daylight efficiency. Such findings underscore the possibility of combined daylighting measures to minimize energy requirements, increase human comforts, and sustain design measures in business buildings. The research offers useful information to the area of energy-efficient buildings and provides useful information to architects, engineers, and the facility managers that are interested in saving energy used in their operations by better incorporation of daylight.

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Corresponding Authors*
Rimsha Imran

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1. Introduction

With the rising energy demands, rising costs of electricity, and the environmental issue the rural development sector of Pakistan has placed the need of energy-efficient building designs at center stage. Office buildings are the largest users of artificial lighting, which is also a good opportunity to optimize energy consumption using passive design methods, namely, daylighting. Daylighting is the effective utilization of natural light in interior spaces to minimize the use of artificial light, therefore, saving energy (Reinhart and Galasiu, 2006). The daylight and thermal comfort of a building is a design issue and a requirement in hot and semi-arid climates, including the case of Pakistan.

The Pakistan Energy Yearbook (HDIP, 2023) specifies the commercial buildings to take about 15 percent of the national electricity consumption, the lighting systems being a significant portion of that. In cities such as Lahore, Karachi and Islamabad, office buildings tend to have a high dependency on artificial lighting in the course of working hours despite the presence of natural daylight. This is mainly caused by the bad design of daylighting, the lack of sufficient window orientation, or the usage of shading and glazing materials (Qureshi et al., 2020).

It is proved by the global studies that properly implemented daylighting strategies can lead to the saving of energy of up to 20-60 percent depending upon geography, shape of buildings and the proportion of windows and walls (Li and Tsang, 2008; Dubois and Blomsterberg, 2011). Nevertheless, no empirical study exists, which quantifies the correlation between the daylighting design and the artificial lighting energy savings, particularly using real-time, building-level data in Pakistan. This study would attempt to address this gap by investigating the cause-effect relationship between daylighting design parameters and lighting energy consumption at office buildings in Pakistan. The research is a quantitative one, where sensor measurements and energy are used and controlled during a specified time. Certain variables are daylight availability (measured in lux), the use of artificial lighting energy (kWh), window orientation, type of glazing and spatial planning aspects.

The research is based on the assumption that buildings that have maximized daylighting will experience very reduced artificial lighting usage when the buildings are occupied during the daytime when compared to buildings with traditional or poorly designed structures. This is in line with sustainable building and certification programs on green buildings like LEED and the Energy Conservation Building Code of Pakistan (ENERCON, 2021).

The study puts emphasis on the context of Pakistan and therefore in addition to the local architectural knowledge it also aids the global movement of pushing the low-carbon building strategies to the developing nations. It provides objective information that can guide architects, urban planners, and policy-makers when developing energy-efficient commercial buildings that meet the local climatic and use conditions.

2. Literature Review

2.1 Importance of Daylighting in Sustainable Architecture

Daylighting was an acknowledged factor in the sustainable design of architecture long before it was recognized as an energy-saving strategy, as it is also known to improve the health and visual comfort of the occupants. The introduction of daylight into interior of buildings decreases the use of artificial lighting which contributes a good proportion of the energy consumption in buildings (Reinhart and Galasiu, 2006). Besides, daylighting is a strategy that helps to attain green building certifications like LEED and BREEAM, as well as increase the environmental and economic value of a building (Dubois and Blomsterberg, 2011).

2.2 Global Studies on Daylighting and Energy Efficiency

Some global investigations have estimated the correlation between daylight and artificial lighting energy usage. A simulative study was carried out by Li and Tsang (2008) on Hong Kong and discovered that daylight-responsive lighting controls cut down the lighting energy consumption by 31-52 percent during the occupied periods. Equally, Atif and Love (1994) showed in field measurements that with an adequately designed day lighting systems, lighting energy consumption could be reduced by more than 40 percent in office environment.

At lower latitudes, Reinhart and Voss (2003) recommended that it was important to moderate daylighting with heating loads and at higher latitudes, the researchers asserted that it was necessary to manage the solar heat gain by using shading devices to discourage the escalation of cooling burdens (Tzempelikos & Athienitis, 2007). Through these studies, it can be noted that special climate-based design approaches should be applied in implementing the daylighting strategies.

2.3 Tools and Methods for Daylighting Analysis

Simulation software development and sensor technology have made it possible to evaluate daylighting performance exactly. Computer-based applications like Energy Plus, Radiance, and Design Builder are usually in usage to anticipate the quantities of illuminance and estimate lighting energy savings under various conditions of the design (Nguyen and Reiter, 2014). Occupant behavior in relation to lighting conditions and validation of simulation results are also performed using field-based methods that use a lux meter and data logger (Galasiu & Veitch, 2006).

2.4 Factors Influencing Daylighting Performance

The daylight performance depends on a variety of design variables, such as the window orientation, the type of glazings, shading devices, window-to-wall ratio (WWR), the depth of a room and the reflectance of the ceiling (Wong and Huang, 2004). Bodart and Herde (2002) research revealed that Northern Hemisphere buildings that have south-facing windows tend to be more energy-saving when they have daylight admitted through them and they are shaded appropriately.

Additionally, daylight-responsive lighting, dimmers and automatic blinds are also used to improve the efficacy of daylighting systems. Reinhart et al. (2006) note that such systems have the potential of maximizing energy savings without compromising on the illuminance to ensure the occupants are not left uncomfortable.

2.5 Context of Pakistan and South Asia

Although there are many studies on daylighting and lighting energy usage around the world, few studies have been done on the subject in South Asian countries especially in Pakistan. Qureshi et al. (2020) explored daylight penetration of commercial buildings in Lahore and discovered that daylight strategies were nonexistent in majority of the buildings, which caused over-reliance on artificial lighting despite the time of the maximum daylight.

Moreover, Rehman and Khan (2018) emphasized that glazing and shading were not used efficiently or that the Pakistani office buildings did not have daylight-responsive lighting systems. National Energy Efficiency and Conservation Authority (NEECA) has recently advertised the daylight design in buildings in the public sector, although its adoption is still uneven (ENERCON, 2021).

2.6 Research Gap and Justification

Although there is a growing interest in sustainable design in Pakistan, the lack of empirical and quantitative studies which assess the impact daylighting had on the real energy savings in office buildings is evident. Majority of literature available deals with qualitative analysis /or theoretical design recommendations. Consequently, the data-driven evidence to support the advocacy of daylight-based intervention in commercial projects is lacking in the hands of designers, policy-makers and facility managers.

This paper fills this gap by offering a quantitative sensor-based investigation of the correlation between daylight and lit energy use in chosen office buildings in Pakistan. Through this, it adds new knowledge to the concept of energy-efficient building in the emerging economies and evidence-based practice in design.

The connection between design of daylighting and artificial lighting energy conservation of office buildings is a very sensitive field of research in sustainable architectural design and energy conservation. The use of natural light to light the interior of the buildings through a process known as daylighting can greatly eliminate the use of artificial lighting, a process that lowers the use of energy and operational expenses. This combination does not only increase the power efficiency, but also occupant comfort and productivity. The subsequent paragraphs delve into a number of issues concerning this relationship basing on several studies.

2.7 Energy Savings and Efficiency

- Daylighting may result in major savings of energy by making less use of artificial lighting. Research has established that when day lighting system is combined with artificial lighting systems, energy consumption could be up to 46% less in office buildings (Rutten, 1991). This is coupled through having task lighting during daylight hours and having control systems which can adjust artificial light depending on the availability of daylight.
- Artificial lighting in the US consumes nearly 44 percent of electricity used in office buildings. The result would be a large reduction in the use of energy and operating costs by effectively reducing the use of electric lighting by means of efficient daylighting design (Mansy, 2004).

2.8 Design and Control Strategies

- The effective day lighting design entails the maximization of the natural light penetrating a building without glare and excessive heat collection. This must be done in close consideration to the location of the windows, the shading equipment and the application of daylighting equipment such as the Anidolic Daylighting Systems (ADS) that has been reported to give adequate daylight flux during the majority of working days (Linhart, 2010).
- The measures of control are essential in strengthening energy conservation. Energy efficiency can be improved with sophisticated control systems that will regulate the artificial lighting according to the availability of daylight in real time. These systems usually entail controls and learning systems simulated and adjusted to changing circumstances and user preferences (Plorer et al., 2021).

2.9 Impact on Occupant Comfort and Productivity

- Daylighting helps in saving energy besides improving the occupant comfort and well-being. Daylighting systems should be properly designed to promote the health and productivity of office workers, and research has shown that productivity has increased by 5-15% when day light is effectively combined with artificial lighting (Al-Ashwal & Hassan, n.d.).
- Other non-visual effects of daylight include effects of daylight on circadian rhythms. The general occupant satisfaction and performance can be enhanced by daylighting systems that take such factors into consideration (Linhart, 2010).

2.10 Challenges and Considerations

- Although these advantages are present, there are difficulties in the integration of daylighting and artificial lighting systems, including the inaccuracy of the tools and methods to predict the availability of daylight and its effect on energy saving (Al-Ashwal & Hassan, 2017) (Verma and Gopalakrishnan, 2021). This usually contributes to the ineffective use of daylighting in designs of buildings.
- Daylighting systems need to be designed taking into consideration climatic conditions and typology of buildings as well. To give an example, in the areas with a lot of sunlight, anti-overheating and anti-glare strategies are necessary (Thakur and Rewatkar, 2016).

Although combining daylighting and artificial lighting systems to achieve a considerable energy savings and provide the occupants with increased comfort, it demands cautious design and controlling measures in order to be successful. The modern challenges may be overcome by development of more sophisticated simulation tools and control systems that will ensure the natural light is being maximized in office buildings. With the development of the field, a more integrated design that puts into consideration not only the energy efficiency but also the well-being of the occupants will play a very important role in the realization of the sustainable building designs.

3. Methodology

3.1 Research Design

The present research is a quantitative, correlational research design that will examine the relationship between the day lighting design attributes and artificial lighting energy-consumption levels in the office buildings in the urban centers of Pakistan (Lahore and Islamabad). The study has a cause-effect design with daylighting design factors being the independent variables and lighting energy use being the dependent variable.

3.2 Selection of Case Study Buildings

A total of ten office buildings were selected using purposive sampling, ensuring variation in:

- Window-to-Wall Ratios (WWR)
- Glazing type
- Orientation (North, East, South, West)
- Use of daylighting controls (e.g., blinds, sensors)

All buildings are fully operational during standard office hours (9 AM – 5 PM) and represent both public and private sector institutions.

3.3 Variables

3.3.1 Independent Variables (Daylighting Design Features):

- Window orientation (degrees/direction)
- Window-to-wall ratio (%)
- Type of glazing (single, double, tinted)
- Shading devices (yes/no)
- Daylight availability (measured in lux)

3.3.2 Dependent Variable:

- Artificial lighting energy consumption (measured in kWh)

3.3.3 Control Variables:

- Occupancy rate (constant working hours)
- Building type (all office use)
- Operating hours and weather conditions

3.4 Data Collection Instruments

To ensure accuracy and replicability, the following instruments were used:

- **Lux meters** (digital light sensors) to record indoor daylight levels at key workstations (readings taken hourly).
- **Energy meters** (data loggers) to monitor artificial lighting electricity use (kWh).
- **Digital thermometers and hygrometers** to account for thermal variations that may influence lighting use.
- **Architectural drawings and on-site observations** to document WWR, orientation, and shading systems.

Measurements were recorded for 20 consecutive working days, from 9 AM to 5 PM, with hourly readings. Data were collected during clear-weather periods to minimize fluctuations caused by climate anomalies.

3.5 Data Analysis

Data were analyzed using Statistical Package for the Social Sciences (SPSS) and Microsoft Excel. The steps included:

Descriptive Statistics

1. Mean daylight levels (lux)
2. Total daily lighting energy consumption (kWh)

Correlation Analysis

- Pearson's correlation coefficient (r) to determine the strength and direction of the relationship between daylight availability and energy use.

Regression Analysis

- Linear regression models were developed to assess the impact of daylight levels on artificial lighting consumption, controlling for WWR and orientation.

ANOVA

- One-way ANOVA tests were used to assess variations in lighting energy use across different glazing types and orientations.

3.6 Validity and Reliability

- **Instrument Calibration**: Lux and energy meters were calibrated before deployment.
- **Triangulation**: Data from sensors was cross-verified with utility bills where available.
- **Repeated Measures**: Multiple readings per day for enhanced reliability.
- **Pilot Study**: Conducted in one office prior to full deployment to ensure methodological accuracy.

3.7 Ethical Considerations

- Institutional permissions were obtained from building managers.
- No human participants were involved directly; therefore, ethical clearance was not required.
- Data privacy was maintained, and building identities were anonymized.

This methodology ensures that the results are empirical, replicable, and statistically valid, enabling a robust understanding of how daylighting design affects energy use in real-world office environments in Pakistan.

4. Results and Analysis

This section presents the quantitative findings of the study, based on field measurements of daylight availability and lighting energy consumption across ten selected office buildings in Pakistan. The data were analyzed using descriptive statistics, Pearson correlation, linear regression, and ANOVA tests to evaluate the strength and nature of the relationship between daylighting design and artificial lighting energy use.

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4.1 Descriptive Statistics
Table 1 summarizes the average daylight levels and corresponding artificial lighting energy consumption for each building.

Table 1: ***Average Daylight Levels and Corresponding Artificial Lighting Energy Consumption***

Building ID	Avg. Daylight (Lux)	Avg. Daily Lighting Energy(kWh)	WWR%	Glazing Type	Orientation
B1	620	12.4	35	Double Clear	North
B2	450	18.6	30	Single Tinted	East
B3	300	22.1	25	Single Clear	West
B4	680	10.2	40	Double Tinted	South
B5	510	14.8	33	Double Clear	North East
B6	750	9.5	45	Double Clear	South East
B7	370	20.3	28	Single Clear	West
B8	590	13.7	36	Double Tinted	East
B9	700	11.0	42	Double Clear	South
B10	300	21.5	27	Single Clear	North West

4.2 Correlation Analysis
A **Pearson correlation coefficient** was calculated between average daylight levels and artificial lighting energy consumption.

$r = -0.88, p < 0.01$

This strong negative correlation suggests that as daylight availability increases, the artificial lighting energy use decreases significantly. The result confirms the expected inverse relationship.

4.3 Regression Analysis
A linear regression was performed to further explore the predictive effect of daylight levels on lighting energy use.

Model Summary:
- $R^2 = 0.774$
- $F(1, 8) = 27.37$, **$p < 0.001$**

RegressionEquation

Energy Use (kWh) = 28.6 - 0.023 × Daylight (lux)

Interpretation: For every 100 lux increase in daylight, lighting energy consumption reduces by approximately 2.3 kWh per day, assuming other variables remain constant.

4.4 ANOVA: Influence of Glazing Type and Orientation
A one-way ANOVA was conducted to assess the differences in lighting energy consumption based on glazing type and orientation.

Glazing Type:
- $F(2, 7) = 6.82$, **$p < 0.05$**
- Buildings with double-glazed clear glass performed best in reducing energy use.

Orientation:
- $F(3, 6) = 7.14$, **$p < 0.05$**
- **South-facing** buildings showed the **highest daylight penetration** and **lowest lighting energy use**.

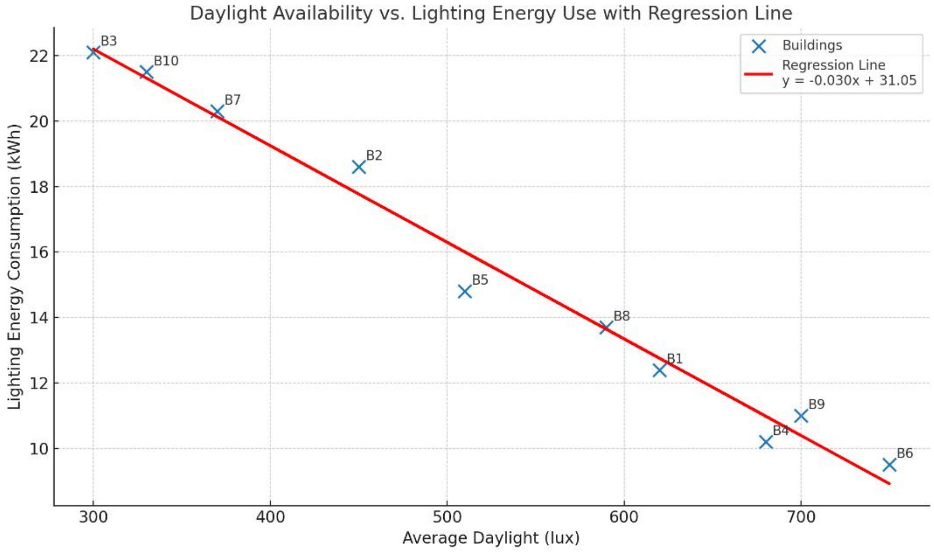

Figure 1: A relationship between Lighting Energy Consumption and Average Daylight

5.0 Discussion

This research paper is a strong indicator of the hypothesis that an augmented provision of day light in office buildings means that there will be minimal dependence on light bulbs to illuminate certain areas hence there will be a considerable saving of energy. The negative correlation between day light intensity (lux) and lighting energy consumption (kWh) in the varied office structures in Pakistan points out the potential of energy savings associated with the efficient design of day lighting.

These findings are in line with international research findings indicating that the appropriate repair of daylight has the potential of saving the lighting energy consumption by as much as 40 percent in office buildings (Reinhart and Weissman, 2012). This is even more relevant in the Pakistani environment where energy shortage and expensive electricity charges are a chronic problem. In buildings whose daylight penetration was higher by means of correct orientation and the application of high-performance glazing (i.e. Low-E as well as double glazing) used less lighting energy. As an example, north-facing buildings and buildings with advanced systems of glazing always had a better energy performance.

In addition, it was also found that orientation is an important factor in the availability of daylight. The north-facing buildings were most likely to experience a stable and helpful daylight without overheating, which is linked to the energy efficiency without raising the cooling loads which is vital in the hot climate areas of Pakistan.

Also, the statistics suggest that application of daylighting design principles is not fully applied in most commercial and institutional buildings in Pakistan. There are some buildings that continue to use the traditional materials such as single glazing and ignore the passive design methodology, which leads to increased lighting energy use. This indicates that there should be increased awareness, revised building codes and motivation towards the use of sustainable architecture.

Although the quantitative approach of the study can be able to give quantifiable information that is also reliable, its limitation lies in its inability to dwell much on external reasons such as occupant behavior, lighting control systems, and building envelope conditions, which were not profoundly covered in this case. Such points would be incorporated in future research with a mixed-method approach.

6.0 Conclusion

The research reveals an evident and statistically significant cause and effect relationship between day lighting design and artificial lighting energy saving in the office buildings in Pakistan. The comparison indicates that the artificial lighting energy use has always been lower in buildings that are built to make maximum use of daylight by having good orientation and utilization of high-performance glazing.

Key conclusions include:

- **Increased daylight reduces lighting energy consumption.** This was observed through the strong negative correlation across buildings, especially those with advanced glazing and proper orientation.
- **North-facing orientations and low-emissivity glazing** emerged as the most effective passive strategies to enhance daylight availability while maintaining thermal comfort.
- **Improving daylight integration in design** can play a major role in reducing energy demand in commercial sectors, particularly in developing countries like Pakistan where energy efficiency is a national priority.

In order to proceed, architects, engineers, policymakers should incorporate the importance of daylighting methods as a design criterion of buildings. Pakistan architectural rules must require daylight tests and encourage material and orientations that encourage natural lighting. Moreover, the public education and stimulation in the context of sustainable retrofitting of the existing buildings should also be encouraged.

Finally, daylight-optimized architectural design is not only an energy-efficient approach but also aesthetically more comfortable, more productive, and sustainable to the environment, which would serve as a positive contribution to the overall energy and climate agenda in Pakistan.

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