CONCEPTUAL DESIGN OF RESIDENTIAL BUILDINGS FOR DAYLIGHT EMPLOYING CONTEMPORARY BEST PRACTICES

[a] Nida Azhar, [b] Faiza Saeed, [c] Farrukh Arif*

a: Department of Urban & Infrastructure Engineering, NED University of Engineering & Technology, nazhar@cloud.neduet.edu.pk
b: Department of Civil Engineering, NED University of Engineering & Technology, faizasaeed@cloud.neduet.edu.pk
c: Department of Civil Engineering, NED University of Engineering & Technology, farrukh@cloud.neduet.edu.pk
* Corresponding author: Email ID: farrukh@cloud.neduet.edu.pk

Abstract- With the increasing energy demands and greenhouse gas emissions, daylight has been considered one of the crucial aspects of passive design strategies to be incorporated in buildings. The literature review indicated a lack of studies to guide the utilization and suitability of such daylight systems for buildings. This article studies contemporary passive daylight incorporating strategies that can be adopted in buildings considering the local context's thermal and visual comfort and privacy. After a thorough review, this study recommends having WWR near 50% for the sun-facing walls with a light shelf and solitude to be part of the conceptual design.

Keywords- Energy Efficiency, Daylight, Building envelope, Residential units.

1 Introduction

Building energy consumption accounts for almost 40% of the world's energy consumption [1]. Current energy production is mainly based on fossil fuels, and its demand is increasing daily across the globe. In Pakistan, an increase in the urban population in recent decades has led to rising energy demand and, consequently, increased carbon dioxide (CO_2) emissions [2]. Several countries across the globe are striving to shift their electricity generation to renewable resources. Still, the downside of this shift is energy from such resources is often inconsistent and intermittent [1].

There can be two aspects to resolving the energy problem: reducing energy consumption and improving the energy efficiency in buildings. While focusing on making buildings energy efficient, passive design strategies can be incorporated to reduce the energy demand of residential buildings. The passive design includes orientation of the main façades and windows, wall thickness, thermal insulation, window details, sunroom for passive solar heating, shading devices, etc. [3]. Passive buildings require less energy as they strike a balance between the heat losses and the heat gains concerning the particular climatic condition of the building's location.

Natural light is vital in improving buildings' environmental quality and energy efficiency [4]. This study is focused on the utilization of daylighting to reduce the consumption of energy during the daytime using relevant passive design strategies. In a residential building, daylight can penetrate through windows, window glasses, or other openings. This study discusses several contemporary practices, which are discussed in detail, can better utilize daylight and reduce energy demand.

Designers need to understand the importance of not only the utilization of daylight but its impact on visual and thermal comfort. A study focused on suitable daylight intensity for local residential units reports that the daylight factor is higher than what is recommended by the Chartered Institute of Building Service Engineers (CIBSE) [5]. Incorporating thermal comfort in design is challenging due to the unavailability of commonly accepted standards. Moreover, no globally agreed glare metric for visual comfort can be applied to various conditions [6]. Therefore, this study provides a conceptual design strategy through a review of contemporary practices. Hence, daylight can be utilized more efficiently in residential designs considering thermal and visual comfort at the same time.

2 Scope

The scope of this study is to study design alterations in building envelopes focused on daylight optimization for residential units keeping in mind the thermal and visual comfort aspects of daylight.

3 Objective

The objective of this study is to propose a conceptual design of a residential unit based on contemporary best practices incorporating thermal and visual comfort and privacy as per social norms.

4 Methodology Design

The review has been conducted from codes, reputed journal publications, and conference proceedings from 2017-2022. The review methodology is focused on a few design alterations such as Window Wall Ratio (WWR), Atrium Solatube, Light Shelf, and Kinetic Shading System.

5 Review of Contemporary Passive Design Strategies for Daylight Utilization

Before discussing the strategies, it is essential to understand how to measure daylight in buildings. The following discussion offers the various methods used for the measurement of daylight. A lux meter can measure the luminance level in a room. Daylight factor (DF) is a daylight availability metric that expresses as a percentage the amount of daylight available inside a room (on a work plane) compared to the amount of unobstructed daylight available outside under overcast sky conditions [7]. Useful daylight illuminance (UDI) is a daylight availability metric that corresponds to the percentage of the occupied time when a target range of illuminances at a point in space is met by daylight [8]. It can be calculated with simulations. Multiple simulation engines are available for daylight analysis; one study used Integrated Environmental Solution-Virtual Environment (IES-VE) for daylight analysis [9]. Notably, desirable illuminance thresholds for residential buildings are still argued. BREEAM and LEED take 300 lux as the benchmark for general visual tasks, and 3000 lux is a typical upper threshold for the overlit issue [10].

Pakistan, a country with many sunny days, can considerably use this resource of natural daylight for its energy demands. Over the years, many passive design strategies have been incorporated to use daylight in residential units efficiently. This study discusses the building envelope aspect of energy efficiency. Since building envelope has been proven essential for decreasing energy consumption and providing thermal comfort and healthy internal spaces [11].

Within the building envelope, the Window to wall ratio (WWR) also needs to be considered in the passive design for better illuminance and proper distribution of daylight. A study of the apartment building in Kathmandu valley recommends that the Window to wall ratio be 24% [12]. ASHRAE 90.1-2010 suggests WWR capped at 40%. WWR for local conditions is suggested to increase from 26% to 50% [13]. As far as thermal comfort is concerned, the increased window size will cause an increase in heat gain because the thermal resistance of the window glass is lower than wall thermal resistance [14]. This issue can be resolved by employing another passive technique and increasing WWR to ensure thermal comfort. For visual comfort, a study found that having less than 50% WWR cause unacceptable visual comfort and illuminance performance. Hence, the recommended WWR ratio will provide visual comfort [15].

Atriums have been proven to increase daylight for many years. It is equally effective today to reduce buildings' energy usage in cold and warm climates by supplying daylight and natural ventilation to interiors if appropriately designed. Atriums, if not, adequately designed atriums can increase energy consumption or cause visual and thermal discomfort [9]. Atrium can have different sizes and geometry. It must be carefully considered because the physical characteristics of the atrium, along with roof configuration, enclosing surfaces, and adjacent spaces, influence the amount of daylight reaching the interior spaces [9]. Due to the complexity of the atrium design, suitable design needs to be explored carefully for the local context before implementation. Therefore, achieving a suitable design of the atrium will lead to a cost-efficient way of making the building energy efficient. Figure 1 illustrates different forms of the atrium.

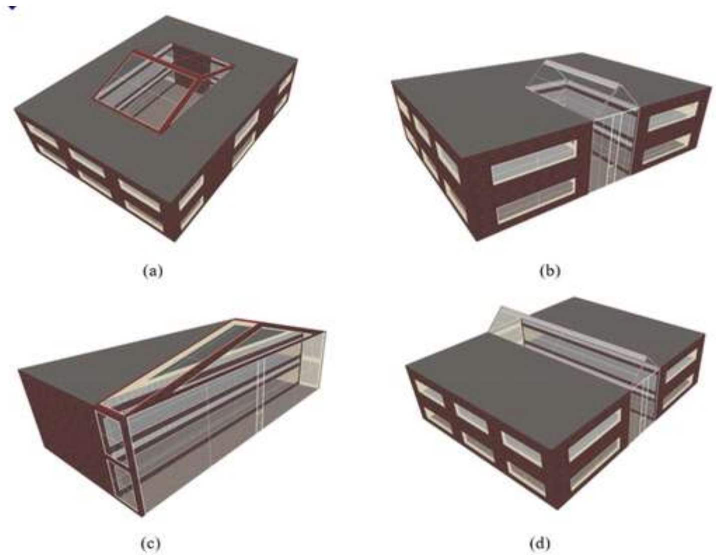

Figure 1: Four forms of atriums [9]

To capture daylight in a building, solatube technology has gained tremendous popularity due to its positive environmental impact and the resulting internal health conditions. The significant advantage of solatube is that it transfers daylight efficiently while blocking excessive heat and providing visual comfort [16]. The basic principle behind the solatube is multi reflections on the highly reflective internal surfaces of the tube. It has three zones, the capture zone, which is the receiving part of the light; the transfer zone, which is the reflecting tube; and the delivery zone, which emits light.

The initial cost of this system is high, and energy savings, in the long run, are not merely enough to make people convinced to use it. Nevertheless, the other benefits solatube offers, such as visual comfort, environment pollution, healthy conditions, indoor environmental quality, and productivity improvements, can make customers inclined towards it [16]. Figure 2 shows the working of a Solatube.

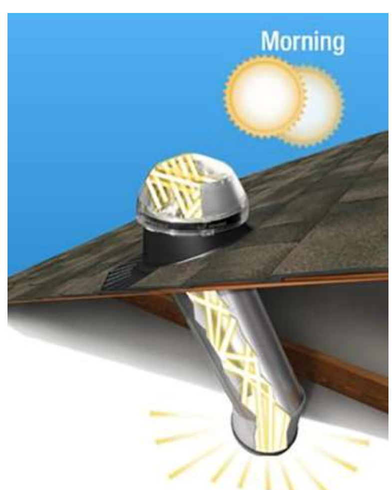

Figure 2 Solatube [16]

A light shelf is one of the light-guiding system (LGS) technology. LGS is easy to install compared to conventional sun shading devices such as solar screens and roller blinds, which block natural light penetration, thus reducing natural light distribution in buildings. LGS reflects, refracts, or deflects sunbeams from facades [17]. Contrary to conventional techniques, they improve light distribution in the room and reduce glare and overheating. If an optimal light shelf is used, thermal comfort can improve up to 81% [18]. Light shelves are also an efficient tool for optimizing and controlling indoor daylight delivery, thus increasing visual comfort [19]. One of the reasons light shelves are gaining popularity in exploration and research during recent years is because light shelves are very cost-efficient solutions to utilize daylight [20]. Figure 3 shows a Daylight reflector.

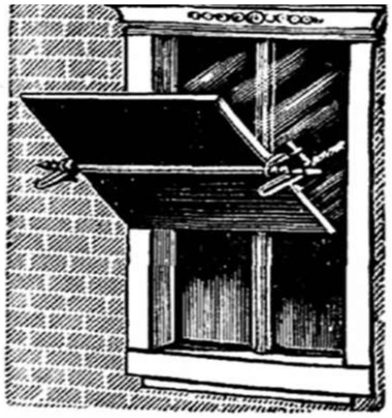

Figure 3: Daylight reflector by W. Hanifch and Co. [20]

A kinetic shading system is another mechanism that works independently and maximizes daylight while preventing direct daylight. A kinetic shading system can decrease the indoor temperature by 2-3 degrees, thus ensuring thermal comfort [21]. This system also diffuses daylight equally, reducing low glare and over-illumination [22], providing visual comfort. Construction cost is the major drawback of kinetic shading systems; otherwise, optimal design for movement and rotation of shader has been achieved [23]. Figure 4 shows an Exterior view of kinetic shading

Figure 4: Exterior view of kinetic shading [22]

6 Discussion and Conceptual Design

Passive design strategies are very effective, and this area has been explored for many years. However, lack of awareness and perception of the high cost hinders it from becoming part of regular residential building design in different world areas [24]. Passive design strategies are climate-sensitive. With the prevailing extreme climate changes, it is challenging to implement strategies evaluated a long time ago. Therefore, relying on contemporary studies is recommended [25].

For hot climates, it is essential to consider daylight variables before simulating design strategies for results, including external shading system, WWR, and type of glazing [26].

According to the design alterations described earlier in this study, different strategies can be compiled in the following Table 1.

Table 1: Comparison of Alternate Passive Design Strategies

Category	Passive Design Element	Initial Cost	Thermal Comfort	Visual Comfort
Light capturing devices	Window to Wall Ratio (WWR)	✓	×	✓
	Atrium	✓	✓	✓
	Solatube	×	✓	✓
Shading devices	Light Shelf	✓	✓	✓
	Kinetic Shading System	×	✓	✓

Since WWR is one of the daylight design variables, studies for local scenarios suggest that recommended size would make better use of daylight. Therefore, it should be part of our residential unit design. It does not have any extra cost of construction, and if coupled with a light shelf, it can counteract the drawback of thermal discomfort due to large windows and reduce glazing. Since windows are already part of an existing design, having windows with light shelves will not cause hindrance from the client for implementation.

Atriums, along with light shelf, is the one that provides thermal comfort and visual comfort at the same time while employing daylight at a lower cost. Consequently, atriums need to be included in our conceptual design.

Solatube is a relatively new design aspect, but its cost is comparatively lower due to less technological intervention. In addition, the solatube also preserves privacy and offers daylight without transmitting heat along with visual comfort.

7 Study Significance

Although much work has been done for daylight utilization, it is not part of our typical designs compared to its full potential. This study gives a brief on five strategies considering daylight significant variables to increase their use in residential designs practically.

8 Conclusions & Recommendations for Future Research

The following conclusions can be drawn from the review:

Considering the local context, complexity, and economy of design alterations, the window wall ratio (WWR) is recommended to be 50% along with a light shelf.

The atrium, an ancient way of daylight utilization, is found to provide thermal and visual at low cost, making it highly suitable to be incorporated in energy-efficient residential design.

Solatube (also called light pipes) can be included in the design to make residential units energy efficient. Despite being costly, they offer many other benefits that surpass the initial cost concern since each penny is worth it.

Kinetic shading systems are equally efficient in daylight utilization. Kinetic shading systems can be explored further for cheaper technological advancement to reduce cost and make it economical to be a part of the design in Pakistan.

This study was limited to a few passive design strategies; this area can be explored further for different strategies available since Pakistan has excellent potential to consume daylight.

Acknowledgment

The study presented in the paper is part of research project NRPU-9626 funded by the Higher Education Commission of Pakistan under its National Research Program for Universities. The corresponding author is PI of the project.

Reference

[1] Nadeem, Ahmad, and Arshad. "PRECON: Pakistan residential electricity consumption dataset." In Proceedings of the *tenth ACM international conference on future energy systems*, pp. 52-57, 2019.

[2] Ghafoor, Zareen, Sharif, U. Khan, Hayyat, Farhan, and Shahzad. "Energy consumption and carbon dioxide emissions of residential buildings in Lahore, Pakistan." *Polish Journal of Environmental Studies* 29, no. 2 pp 1613-1623, 2020.

[3] Omrany, Hossein, and Marsono. "Optimization of building energy performance through passive design strategies." *British Journal of Applied Science & Technology* 13, no. 6, pp 1-16, 2016.

[4] Fadle, M., Abu, M., Lukman, N. I. K., Ibrahim, N. I. K. & Sopian, K. "The Performance of External Shading Devices and Daylighting Rule of Thumb for a Tropical Climate of Thumb". *Latest Trends in Renewable Energy and Environmental Informatics,* 130–134, 2013.

[5] Yousuf, Sumra, Alamgir, Afzal, Maqsood, and Arif. "Evaluation of daylight intensity for sustainbility in residential buildings in cantonment cottages Multan." *Mehran University Research Journal of Engineering and Technology* 36, no. 3 597-608, 2017.

[6] Shafavi, Seyed, Zomorodian, Tahsildoost, and Javadi. "Occupants visual comfort assessments: A review of field studies and lab experiments." Solar energy 208, 249-274, 2020.

[7] Hopkinson, Galbraith. "Architectural Physics: Lighting." 1963.

[8] Samadi, Sahba, Noorzai, Beltrán, and Abbasi. "A computational approach for achieving optimum daylight inside buildings through automated kinetic shading systems." *Frontiers of Architectural Research 9*, no. 2, 335-349, 2020.

[9] Omrany, Hossein, Ghaffarianhoseini, Berardi, Ghaffarianhoseini, and HW Li. "Is atrium an ideal form for daylight in buildings?" *Architectural Science Review* 63, no. 1, 47-62, 2020.

[10] Ji, Guanzhou. "Daylight Availability And Occupant Visual Comfort In Seattle Multi-Family Housing." *ASHRAE Topical Conference Proceedings*, pp. 93-102, 2020.

[11] Al-Qahtani, Elgizawi, "Building envelope and energy saving case study: a residential building in Al-Riyadh, Saudi Arabia", *International Journal of Low-Carbon Technologies*, 15, 04, pp 555–564, 2020.

[12] Sangraula, Birat, and Uprety. "Window to wall ratio for daylighting in context of apartment building in Kathmandu valley." *Journal of Building and Environmental Engineering*, 08-14, 2020.

[13] Arif, Khalid, and Azhar. "Identification of Energy Efficiency Improvement Measures of an Existing Residential Building Using Audit-Assisted Energy Simulation and Analysis." *Engineering Proceedings* 12, no. 1, 18, 2021.

[14] Elghamry, Rania, and Hamdy Hassan. "Impact of window parameters on the building envelope on the thermal comfort, energy consumption and cost and environment." International Journal of Ventilation 19, no. 4, pp 233-259, 2020.

[15] Ochoa, Carlos, Aries, Loenen, and Hensen. "Considerations on design optimization criteria for windows providing low energy consumption and high visual comfort." *Applied energy* vol 95, 238-245, 2012.

[16] Balabel, A., M. Alwetaishi, A. Abdelhafiz, U. Issa, I. A. Sharaky, A. K. Shamseldin, M. Al-Surf, and M. Al-Harthi. "Potential of Solatube technology as passive daylight systems for sustainable buildings in Saudi Arabia." *Alexandria Engineering Journal* 61, no. 1, 339-353, 2022.

[17] Wong, Liang. "A review of daylighting design and implementation in buildings." *Renewable and Sustainable Energy Reviews* 74, 959-968, 2017.

[18] Ebrahimi-Moghadam, Amir, Ildarabadi, Aliakbari, and Fadaee. "Sensitivity analysis and multi-objective optimization of energy consumption and thermal comfort by using interior light shelves in residential buildings." *Renewable Energy* 159, pp 736-755, 2020.

[19] Bahdad, Salem, Fadzil, Onubi, BenLasod. "Sensitivity analysis linked to multi-objective optimization for adjustments of light-shelves design parameters in response to visual comfort and thermal energy performance." *Journal of Building Engineering*, 44, pp 102996, 2021.

[20] Kontadakis, Antonis, Tsangrassoulis, Doulos, and Zerefos. "A review of light shelf designs for daylit environments." *Sustainability,* 10, no. 1, pp 71, 2017.

[21] Ahmed, Mostafa MS, Ali K. Abdel-Rahman, Bady, and Mahrous. "The thermal performance of residential building integrated with adaptive kinetic shading system." *International Energy Journal,* 16, pp. 3, 2016.

[22] Ahmed, M., Rahman, Bady, E. Mahrous, and M. Suzuki. "Optimum energy consumption by using kinetic shading system for residential buildings in hot arid areas." *International Journal of Smart Grid and Clean Energy*, 5, no. 2, 2, 2016.

[23] Samadi, Sahba, Noorzai, Beltrán, and Abbasi. "A computational approach for achieving optimum daylight inside buildings through automated kinetic shading systems." *Frontiers of Architectural Research*, 9, no. 2 pp 335-349, 2020.

[24] Alkali, M. A., Jie, Dalibi, and Danja. "Hindrances to the Utilization of Climate Responsive Architecture Principles for Residential Design in Northeast Nigeria." *environment*, 9,pp 10, 2020.

[25] Wang, Shangyu, Liu, Cao, Li, Yu, and Yang. "Applicability of passive design strategies in China promoted under global warming in past half century." *Building and Environment*, 195, 2021.

[26] Al-Dossary, Mohammed, and Kim. "A study of design variables in daylight and energy performance in residential buildings under hot climates." *Energies*, 13, no. 21, 5836, 2020.