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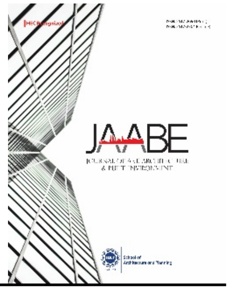

Title: **Enhancing Energy Conservation, Visual and Thermal Comfort in Small Houses of Karachi**

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Enhancing Energy Conservation, Visual and Thermal Comfort in Small Houses of Karachi

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Abstract

The significance of housing in developing cities cannot be overstated, as individuals strive to acquire and own physical assets throughout their lives, even in the case of small plots as modest as 80 square yards. In urban areas such as Karachi, smaller houses ranging from 80 to 240 square yards mostly are predominantly constructed by contractors or by owners themselves. This is to avoid additional fees charged by architects who may tailor the design to suit the context and specific requirements. Consequently, these houses tend to exhibit a similar layout, maximizing the utilization of allowable space as stipulated by the bylaws. However, this approach often leads to limited natural ventilation and daylighting, resulting in increased energy consumption for thermal and visual comfort. Hence, the current research underscores the urgency of addressing the prevailing lack of natural ventilation and daylighting in these houses. To address these concerns, it presents a comprehensive framework of passive strategies aimed at enhancing the thermal and visual comfort of occupants. Firstly, an archival study was conducted, encompassing a comprehensive literature review, which served as a foundation to understand the subject matter. Secondly, a comparative study was undertaken to examine conventional small house typical plans prevalent in Karachi. This study was followed by the formulation of proposals for improved planning. Various secondary resources were utilized to support the comparative analysis of two typical house plans in Karachi, in conjunction with the proposed passive strategies. Through the application of these strategies, occupants can benefit from improved comfort, reduced energy consumption, and heightened well-being.

Keywords: occupant's comfort, passive strategies, reduced energy consumption, health and wellbeing, urban cities

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Introduction

Karachi, being the economic hub of Pakistan, attracts individuals from various cities, thus offering a diverse living environment in the country's metropolis. In Pakistan, owning a house is culturally essential, plus with the ever-increasing rents this now become a necessity. The ability to avoid rental payments contributes to a more manageable daily life pattern (Hasan, 2008). Moreover, owning a house is considered as a significant investment due to the high demand of residential plots and consequent substantial increase in land prices over the years. Even the acquisition of a small plot is perceived as a dream come true and requires substantial savings an average citizen. In Karachi, particularly among the middle-income group, individuals tend to purchase smaller houses within their budgetary constraints. As the market society expands, houses and plots transform into commodities in urban areas. Their longevity and resale potential makes them valuable assets for owners and investors alike. Common people invest their entire savings to purchase a plot and build a house on it, often opting to forgo technical assistance from architects or other experts to minimize cost. In order to accommodate large families or generate rental income, they maximize the utilization of the available plot space, inadvertently compromising natural light and ventilation within the house (Lodhi & Pasha, 1991). The Karachi Development Authority (KDA) building regulations allow for this provision in smaller houses, enabling the maximum coverage of the plot. However, long-term absence of ventilation and natural light not only increases energy bills but also leads to thermal discomfort for occupants, resulting in various physiological and psychological ailments (Nelson, 2018). Farmer and Guy (2008) stated that "the utilization of natural methods and reduced reliance on mechanical techniques is regarded as the most effective approach to minimize energy consumption in building services".

Karachi is renowned for its south-western breeze, blowing predominantly in a direction of 245 degrees and contributing to the city's pleasant climate for a significant portion of the year. Consequently, the residential zone in Karachi is predominantly planned in an east-to-west direction, with facades perpendicular to the prevailing wind direction to facilitate natural ventilation (Ahmed, 2022). Plots in Karachi are typically aligned either east or west in the row-to-row housing arrangement, with west-facing plots commanding higher demand in prices as compared to their counterparts.

This research paper aims to propose a framework for passive strategies, if incorporated during the construction of small, attached houses in Karachi, can enhance natural ventilation, lighting, and long-term affordability of living costs. The key objectives are to recommend suitable passive strategies for small, attached houses that may reduce energy bills, promote energy conservation, and provide thermal and visual comfort for the occupants.

Literature Review

Due to the escalating costs of energy, affording fuel expenses associated with mechanical systems used to control indoor environmental quality has become increasingly challenging. Consequently, contemporary architectural practices must prioritize optimal house design solutions to ensure the thermal comfort of occupants. This necessitates an exploration of diverse passive design strategies that can mitigate the adverse effects of outdoor climatic fluctuations on the interior environment of a house (Ameur et al., 2020). Daylighting and ventilation emerge as pivotal features in a passive house design, not only enhancing visual aesthetics and thermal comfort but also fostering the physiological and psychological well-being of occupants (Tabadkani et al., 2018). Passive house design operates on the fundamental premise of meeting functional requirements for thermal comfort through natural ventilation systems and controlled maximum light exposure. Essentially, a passive designed house achieves thermal comfort solely by pre-conditioning or post-conditioning the fresh air mass, thereby maintaining optimal indoor air quality without the need for additional air recirculation. Additionally, it ensures appropriate natural light levels to alleviate reliance on artificial lighting sources (Ameur et al., 2020).

Climate Change and Impact of Current Housing Situation in Karachi

Karachi is characterized by a subtropical arid climate and experiences mildly hot summers with high humidity levels. Often, a combination of temperature and humidity results in a perceived temperature exceeding 40 degrees Celsius, despite actual temperature typically ranging around 34 to 35 degrees Celsius. One notable aspect of Karachi's weather is the prevailing southwesterly wind which persists and helps moderate the temperature, especially when individuals seek shelter under shade (Shaheen et al., 2016). However, in recent years, Karachi has witnessed several heatwaves due to climate change, particularly since 2015, leading to uncomfortable temperatures. Improper construction practices, where houses cover most of the allowable plot space, contribute to the lack of natural ventilation and light within residences. Consequently, the use of air conditioning systems and artificial lighting has increased significantly to maintain a comfortable indoor environment for the occupants (Hanif, 2017). Unfortunately, many urban residents fail to grasp the long-term implications of such conditions, as they result not only in increased monthly energy bills but also in adverse physiological and psychological health effects.

Natural Ventilation

Natural ventilation is preferred in low rise, shallow plan buildings, such as houses, schools, healthcare centers, and small office units. It is not recommended for deep plan buildings as air becomes stale and contaminated long before it can be moved out. Passive energy efficient buildings use effective natural ventilation as a primary strategy to maintain human thermal comfort. Studies suggest that natural ventilation in the built environment reduces energy consumption and greenhouse gas emission. Furthermore, it increases the level of thermal comfort in both indoor and outdoor environments (Kubota & Ahmad, 2006). A comparative study of electromechanical and natural ventilation indicates that using the latter in mixed mode systems achieves 18% savings in health costs (Brager & Baker, 2009). A study by Fisk (2002) indicates that the sick building syndrome in office buildings can be reduced by the use of fresh air, thus saving around 10-30 billion USD in the USA alone. The same concept can be applied on residential buildings with a higher indoor air quality index to achieve better thermal comfort through fresh ventilation. In a nutshell, natural ventilation in a building can achieve reduced utility bills, increases thermal comfort, and provides better air quality. Further, it also ensures the physical and psychological health of the occupants. Moreover, it significantly improves cooling and minimizes heat absorption from the environment, although only when considerations are done well in time in the primary stages of construction (Aflaki et al., 2015).

Air Well Design

Air well design helps the air flow to circulate vertically replacing the hot air with cool fresh air through the stack effect. It ventilates the building by taking in fresh air through openings and by discharging the polluted air through the vertical opening in the building, from the lowest level to the rooftop. This process faces some limitations including the possibility of insects and dust from the outside, as well as an uncontrollable air flow or a limited one where the wind is low (Brohus et al., 2003). Still the air flow can be achieved through air wells and stack air duct as alternatives for small sized structures for ventilation. Whereas, for larger buildings, the purpose is fulfilled by using an atrium. The passive cooling effect can be enhanced by adding water bodies or green patches to provide cool air flow in the buildings, although water bodies should be avoided in humid climates (Haase et al., 2009) like that of Karachi. As per Caravane Earth (2022), courtyard is the soul of a building and a house without a courtyard is like a soulless man. It should be the protagonist of greenery and nature around which the house is to be built to make it healthier and relaxing for the occupants. Courtyard or air well integration is energy efficient in all climates, especially hot arid and hot humid climates. Previous researches proved that the integration of courtyard with cross-ventilation increases significantly the cooling of interiors and impacts energy reduction (Aldawoud & Clark, 2008; Al-Hemiddi & Al-Saud, 2001; Clarke & Reardon, 2015).

Ventilation through Fenestration

Openings play an important role in directing fresh air into the house. These openings can be designed on the house envelop, especially façades, other elevations, and the roof and perform controlling functions for the inflow and outflow of air into the house, while maintaining the indoor air quality to the best (Okba, 2005). The optimal results of reduced cooling loads can be achieved significantly by designing these openings with proper understanding. The openings also control the access to both daylighting and ventilation and help to save energy costs on artificial daylighting and mechanical ventilations (Aflaki et al., 2015). Windows, clerestory, vents, skylights, and louvers can be various forms of openings dependent on architectural design requirements as well as the indoor activity of the occupants. Their size, orientation, and placement also contribute to achieve the airflow in the house, facilitating it to get natural ventilation (Roulet & Ghiaus, 2005). To ensure good distribution within a built space, wall openings should be designed with high porosity, or the built space should have a high percentage of openings on both windward and leeward sides for cross-ventilation. Ideally, solar path and breeze should coincide to achieve the best results. This helps to achieve cross-ventilation and exhaust air can be removed easily from the house through stack effect. For a single or double floor deep plan building, roof outlets can be made for natural ventilation though ceiling fans remain necessary to achieve thermal comfort in summers (Su & Aynsley, 2006).

Orientation of the Building

Building orientation plays a very important part in integrating natural ventilation. For this purpose, it is necessary to study the wind pattern, direction, and exposure of the building to obtain maximum ventilation (Anselm, 2006). For natural ventilation, the buildings should be oriented to maximize the wind flow. Moreover, they should be designed with a narrower plan to minimize resistance airflow through the building for cross-ventilation. Right orientation can change thermal comfort up to 8.5-9.5% (Pathirana et al., 2019). This is why city planning in Karachi directs the houses to be perpendicular to the wind direction, lay outing itself on the east to west in depth (Ahmed, 2022). When buying a house in Karachi, it is advised to prefer the ones with west direction façade, to have an airy house and to save on air conditioning bills in summers. The real estate brokers play with the psyche of people to increase the cost for houses on the west side direction. Although, if the house is planned well and oriented as per the wind, both west and east side houses can be equally good options for occupant's comfort in a house.

Impact of Vegetation

Vegetation can be used to enhance ventilation and cool incoming air. Moreover, it also helps to modify the outdoor wind direction. Carefully selected grass berms and shrub cover can be used to direct the wind for natural ventilation and cool the air through evapotranspiration. Further, green cover also reduces micro temperature by shielding the ground from solar radiation (Aynsley, 2014). Space constraints further reduce the applicability of green surfaces in various areas surrounding the building envelope. Consequently, planted roofs and patios remain the only promising and stabilizing choice in this scenario. Good thermal protection can greatly reduce high thermal loads that badly affect the comfort conditioning of buildings during summers. Adding vegetation on terraces, openings, window sills, courtyards, and rooftops help to create a comfortable micro climate for any house, especially the green cover on the terrace and rooftop helps to reduce the thermal mass of the house and allows the cooler breeze to enter into the house (Raji et al., 2015). Plant cover is also helpful in healthy surroundings. It generates pure oxygen and absorbs exhaust carbon dioxide. A study by Givoni and Bagneid specified that outdoor spaces and internal patios not only provide a pleasant outdoor environment but also improve the indoor thermal conditions. A courtyard or patio with high shrubs, vines, or plantation lowers air temperature and improves indoor air quality by trapping the cool air for the adjacent spaces (Bagneid, 1992; Givoni, 1994).

Natural Lighting

Daylight is recognized as a crucial element in sustainable architecture, offering one of the most effective strategies to optimize building energy consumption. Implementing a well-developed daylight design system can significantly reduce a building's reliance on electrical lighting, thereby promoting energy efficiency while providing visual comfort for the occupants, simultaneously. Furthermore, day lighting positively influences indoor lighting quality and contributes to economic and bioenvironmental advantages within residential buildings (Moazzeni & Ghiabaklou, 2016).

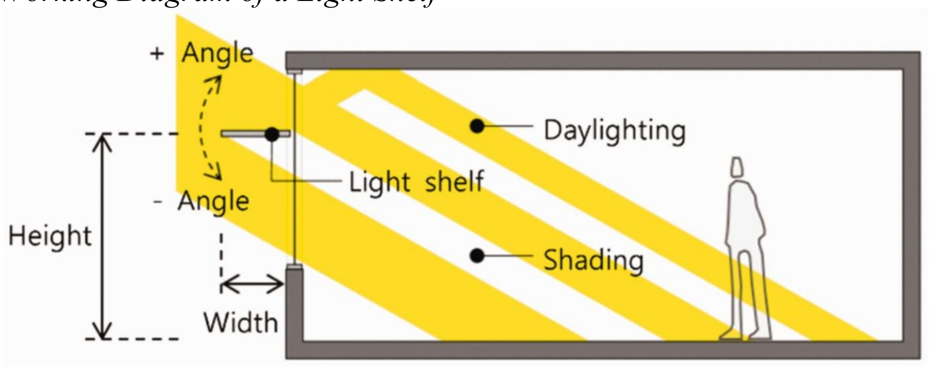
The human circadian rhythm is intricately linked to natural light, exerting a profound impact on various physiological functions including mood, sleep patterns, and appetite regulation (Skafida, 2019). By thoughtfully orienting buildings and openings in different directions, the desired natural lighting level can be achieved without causing discomfort. Indirect or diffused natural light is often preferred as it effectively illuminates interior spaces, avoiding issues such as glare and overheating that may arise with direct natural light (Boubekri et al., 2020). Given that individuals spend approximately 87% of their lives within building envelopes. Arguably, relying solely on conventional electrical lighting sources can adequately fulfill functional lighting requirements but such sources cannot synchronize with the human circadian system. Thus, incorporating well-designed natural lighting into interior spaces reduces the reliance on artificial lighting during daylight hours, leading to decreased energy costs and promoting the overall well-being of the occupants. The availability of natural light enhances the human circadian rhythm, resulting in physiological and psychological health benefits (El Monayeri & Alkhozondar, 2015).

While daylight offers numerous benefits, it is important to address potential discomforts associated with its use, such as glare and unwanted reflections (Boubekri et al., 2020). These factors can disrupt thermal comfort and lead to overheating. However, a competent lighting designer should have the expertise to strike a balance and achieve effective daylighting while mitigating potential discomforts, thus minimizing energy consumption and optimizing its benefits.

Light Shelf

The effectiveness of light shelves has been acknowledged in relation to their significance as a solution to the lighting issue. Light shelves are natural lighting systems that bring in direct sunlight deeper inside the building from the outside through reflection. They show a better performance at the southern orientation as compared to other orientations. By increasing the size of the internal and external light shelves, daylight areas can be distributed more appropriately and increased by 40%, as compared to shelf less conditions (Moazzeni & Ghiabaklou, 2016).

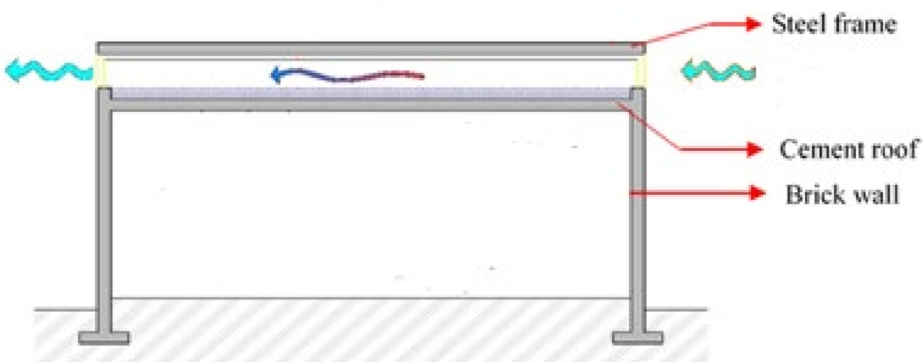
Figure 1
Working Diagram of a Light Shelf



Solar Shading Roof

Solar heat gain has been identified as one of the major contributors to overheating in residential buildings. Therefore, minimizing solar heat gain can improve the effectiveness of natural ventilation. Solar shading roof is a technique used to provide a double roofing system with a metal surface, so that the one directly over the occupied space is not exposed to direct sunlight. The metal surface gaining heat through direct sunlight, the heat gained can be easily removed through ventilation from the sides. This technique not only improves thermal comfort for the occupants but also causes a major increase in energy saving. Further, it also reduces the heat index and improves the indoor environmental quality of the built space. The topmost floors usually get heated because of direct radiation and become very uncomfortable for the occupants. This technique is helpful to maintain the thermal comfort of the occupants on the topmost floor of the building, providing it at the height of 7 feet will make the roof usable for the traditional occupations in households leaving a usable rooftop. The results of a research conducted though simulations revealed that shading strategies are the most effective during the hottest periods of the year and reduce the risk of extreme overheating by up to 52% (Hashemi & Khatami, 2017). This method is effective for both winters and summers with vents and without vents, respectively. In the case of Karachi, the weather condition is either hot or warm for more than ten months and the winters are mild. Thus, the application of this strategy without vents would be a better and more affordable technique to employ in houses. Using this technique on the livable space (giving it the height of at least 6.5') can make the rooftop useable for the occupants to enjoy their spare time and grow a roof garden.

Figure 2
Solar Shading Roof System Assembly



Methodology

The research methodology employed in this study encompasses two key techniques. The first technique involved secondary research conducted through an extensive literature review. The literature review explored various types of passive design strategies that can be implemented to enhance the living conditions of small houses. The review examined how these strategies have been effective in improving ventilation and natural lighting. By drawing upon a wide range of scholarly sources, this secondary research approach provided a solid foundation for the proposed solutions.

The second method utilized in this research was a comparative study of typical plans of conventional small houses prevalent in Karachi. This involved analyzing existing house designs in the city, while juxtaposing them with the proposed solutions derived from the literature review as well as the authors' own observations. By conducting the comparative analysis, the current research aimed to shed light on the significance of adopting passive strategies for small houses, which are typically constructed by owners or contractors without technical expertise. Further, it also aimed to provide a framework for better design options for such houses.

Comparative Case Studies

Conventional Small House Plans in Karachi

In Karachi, the smallest plot size allowed in any new plotting area is 80 sq. yards. The 80 sq. yards house is allowed to cover the whole plot space without any compulsory open space, as per the bylaws. Whereas 120 sq. yards to 200 sq. yards houses must leave a compulsory open space of almost 30%, mostly on the front and the rear. In this research, two sample plans of 120 and 200 sq. yards houses were taken into consideration to propose passive strategies for smaller housing units. The benefits of covering most of the space for the occupants are shown below in Figure 3 and Figure 4, respectively.

These houses have major issues of ventilation and sunlight. This is especially true for the ground floor, since its direct access to ventilation and sunlight is minimized due to negligible open spaces. This is because most of the owners want to build a house with maximum space to cover. Further, due to adjacent houses on both sides, ventilation from the sides is not possible at all. In this phase of construction, the major aim is to have more rooms in the house, rather than their ventilation or exposure to sunlight. As a result, these spaces are poorly ventilated. Hence, they need air conditioning systems and constant use of artificial lighting to provide thermal and visual comfort. This results in ever increasing energy bills that go beyond affordance and raises the heat island index of the surroundings. In the long run, it also causes physiological and psychological illnesses among the occupants.

Figure 3

Conventional Plan of 120 Sq. Yards House

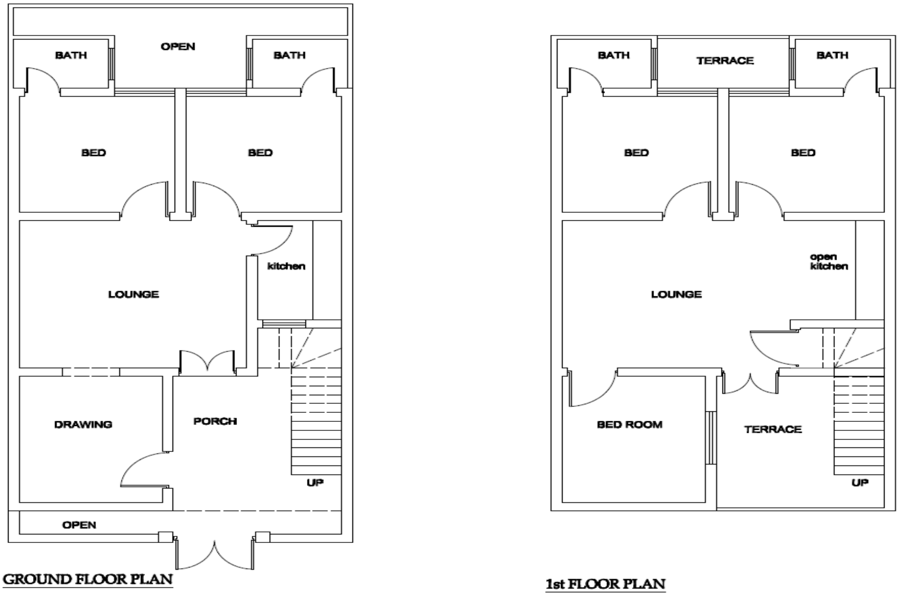
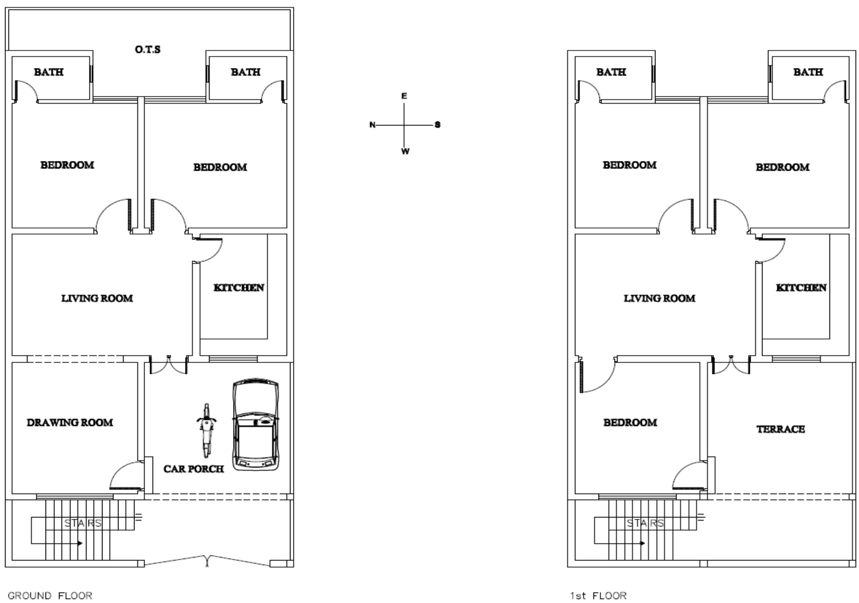


Figure 4

Conventional Plan of 200 Sq. Yards House

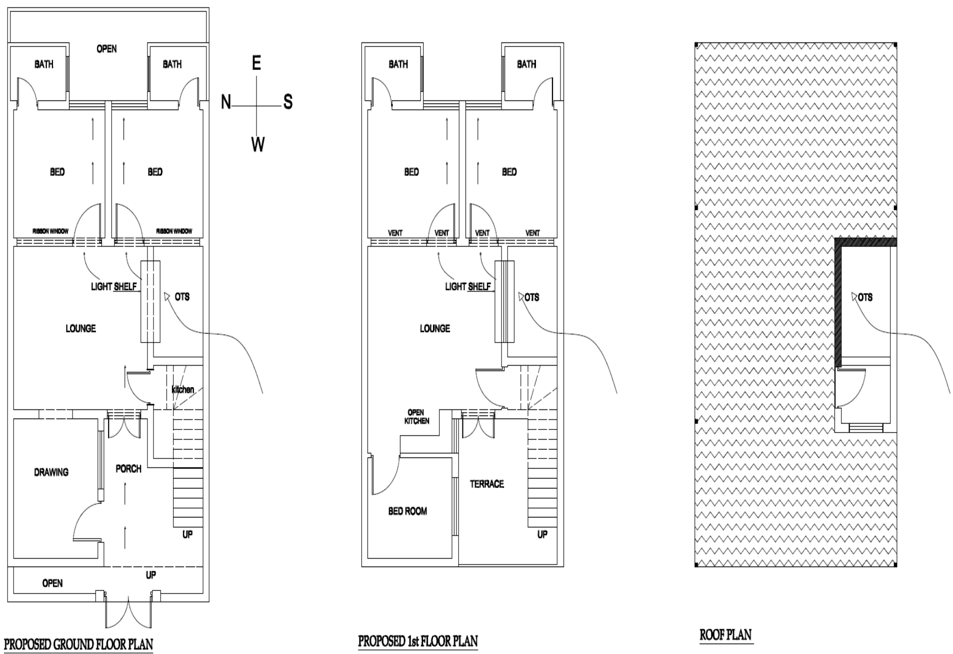


Proposed Passive Design Small House Plans for Karachi

A comparative proposed plan is given in response to conventional plans. It keeps the maximum space requirement in consideration and offers a solution to ensure ventilation and access to natural daylight for households. The proposed plans may not be ideal spatial divisions given by the architects during the normal design process. Still, they cater to the main concern of households to cover the maximum available space, while considering the incorporation of passive design strategies.

Figure 5

Proposed Plan for 120 Sq. Yards House using Passive Strategies



The plan proposes similar number of rooms and terraces as the conventional plan. However, the lounge space is mildly compromised to add an accessible patio (air well) with vegetation. It acts as a wind facing shaft on the windward side, which is the south-western side. This space can easily be used as an open sitting space connected to the lounge on the ground floor. Thus, the space which was initially sacrificed can be used well. The Ribbon windows are proposed above door heights on the entrance and the bedroom walls, so that cross-ventilation can be created, and the house gets naturally ventilated without disturbing the privacy of the occupants. The backyard acts as the shaft that removes the exhaust air from the house through stack effect. Figure 7 shows the expected wind pattern with the help of the patio and the backyard shaft.

Figure 6

Proposed Plan for 200 Sq. Yards House using Passive Strategies

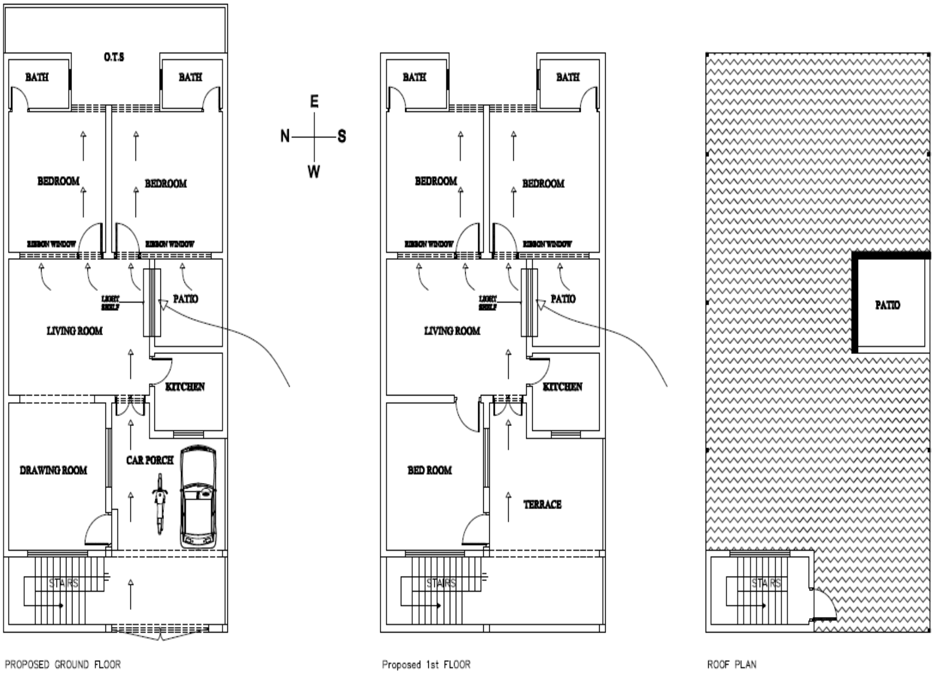


Figure 7

Expected Air Flow

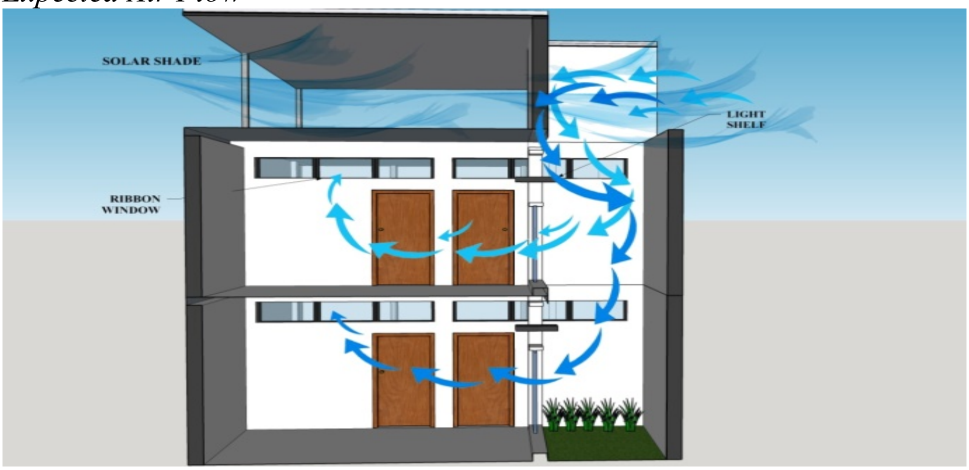
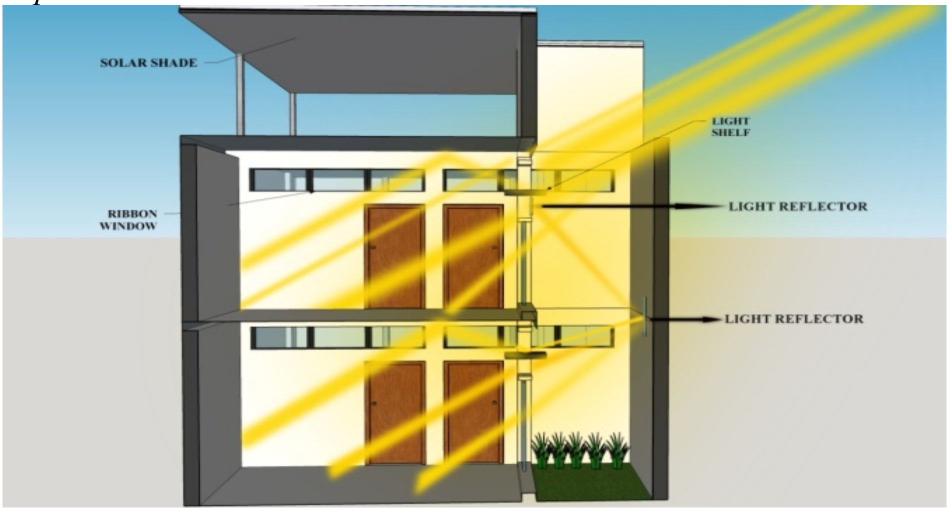


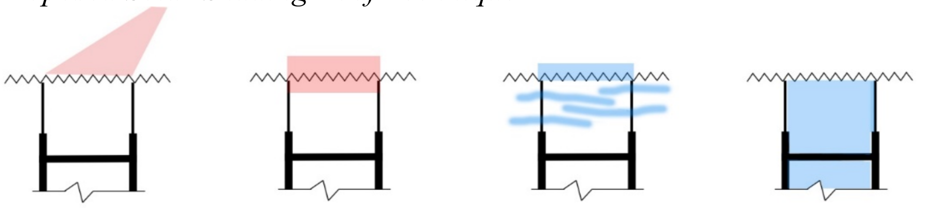
Figure 8
Expected Solar Pattern



For natural lighting, the outer rooms would receive the light from the front and the backyard space. Still, the lounge space and part of the bedrooms would be in the darkened area. To solve this problem, a light shelf is proposed on the openings of the patio to provide a deeper access to natural light through reflection. To keep the ground floor well-lighted, light reflectors and light shelf are used on the patio to reflect the sunlight in order to bring it inside. Figure 8 shows the expected light pattern through the patio with the help of the light shelf and light reflectors.

Solar shading roof is proposed on the rooftop to cool off the occupied space below through ventilation from the sides. Since Karachi has mostly ten months of hot weather, no vents are needed to provide heating for winters. Thus, the incorporation of solar shading roof would be a cheaper option. The proposed material covering can be metallic so it can be cooled off easily. It can also be a onetime investment of solar panels which can provide a further energy saving option, as per the occupant's affordability.

Figure 9
Proposed Solar Shading Roof Technique



Conclusion

The study concludes that these simple measures would facilitate small houses to attain natural ventilation and daylight, thus providing an effective means of saving energy bills as well as providing thermal and visual comfort for the occupants. Some of the proposed passive strategies may seem like an added investment at the time of construction. However, in the long-term, these would prove to be very affordable due to decreasing living costs, without compromising natural ventilation and daylight. The concept is based on obtaining maximum benefits from the surrounding climate conditions, building placement, and the use of locally available construction materials to meet indoor thermal comfort needs, with minimum energy consumption for air conditioning and artificial lighting. In the long run, this would not only decrease the medical bills but also impact the overall health of the occupants, resulting in more disposable income for the occupants to use on their own wellbeing. Thus, this paper proposes that passive strategies, if used in the small, attached houses in Karachi, can increase natural ventilation and lighting in these houses. This in the long run would decrease the living cost, save on the energy bills and provide visual, thermal comfort and health benefits for the occupants of the house.

Scope and Limitations of the Research

The current research can be subjected to further scrutiny through experimentation utilizing both practical methods and technologies, as well as computer-based simulation techniques. This study is more of an observational study on the available design solutions which can make the life of the occupants better than usual. These solutions are provided by professionally trained and practicing architects. Their application can provide valuable data to strengthen the findings and recommendations put forth in this paper regarding passive strategies. The proposed strategies should be tested through simulations in different scenarios to determine the amount of ventilation and sunlight. Additionally, future studies may focus on investigating the optimal sizes and materials for the proposed passive strategies, such as solar shading roofs, openings, air wells, and light shelves. Different sizes and materials may yield varying outcomes, necessitating a meticulous analysis to determine the most suitable strategies in specific contexts.

Moreover, an alternative avenue of inquiry may involve assessing the comparative capital costs and ongoing living expenses associated with implementing these passive strategies in real-world scenarios. By examining these factors in situ, a more comprehensive and reliable analysis can be conducted to substantiate the assertions made above in a more credible manner.

Conflict of Interest

The authors of the manuscript have no financial or non-financial conflict of interest in the subject matter or materials discussed in this manuscript.

Data Availability

The data associated with this study will be provided by the corresponding author upon request.

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