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Exploring Bioclimatic Architecture for Rural Housing Solutions in Mirpurkhas, Sindh

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ABSTRACT

The domestic sector consumes a substantial portion of global energy resources, making it essential to understand, evaluate, and implement bioclimatic architectural techniques that reduce energy consumption. Bioclimatic design, a sustainable approach, considers both climatic conditions and human needs to determine the feasibility of architectural solutions. This research explores bioclimatic principles aimed at enhancing comfort and economic efficiency in residential buildings. By adopting passive and active strategies, such designs not only address the energy crisis but also help mitigate environmental degradation. A range of methodologies—such as case studies, surveys, interviews, questionnaires, and computational modeling—are employed to propose effective bioclimatic design strategies. The findings highlight the relevance of bioclimatic architecture in rural settings, particularly in Mirpurkhas, where abundant natural resources have historically been underutilized due to a lack of awareness and education. The study demonstrates that general bioclimatic design principles can lead to substantial energy savings and that successful strategies from specific regions can be adapted and transferred to other areas with similar climatic conditions.

Introduction

A house serves as a shelter, protecting from the sun, wind, snow, various climatic conditions, and other living organisms such as animals and insects. The terms "house" and "shelter" can often be used interchangeably. Beyond physical protection, a shelter contributes to a sense of well-being and plays a vital role in supporting one's psychological resilience and will to survive (Karanja, J., et al. 2023). Individuals exposed to the elements for extended periods often experience exhaustion and a loss of hope. Therefore, having shelter significantly enhances one's quality of life. A shelter is more than just physical protection—it serves as a space for family interaction and provides a nurturing environment for the healthy upbringing of children (Cassum, L. A., et al. 2020). Having shelter provides residents with a sense of security, allowing them to focus on other important aspects of their lives. It fosters personal independence and offers a degree of privacy from the broader community. Just like food, water, and clothing, shelter is a fundamental human necessity (Wagemann, E., 2017).

Study Area

Mirpurkhas is a taluka city and the administrative capital of Mirpurkhas District in Sindh, Pakistan. As the fourth largest city in the province, it spans an area of approximately 1,088 km² and had an estimated population of 198,162 in 2014. The broader district covers 2,925 km² with a total estimated population of 1,592,981. Known for its fertile soil, Mirpurkhas is famous for its horticultural produce, particularly its mango cultivation, which includes hundreds of mango varieties harvested annually. Strategically positioned as the southeastern gateway to Sindh, the city lies on the Mirwah Canal at coordinates 25°31′39.3″N, 69°00′50.6″E. While it is directly connected to Umerkot by road, it is 65 kilometers from Hyderabad via both road and rail, and approximately 220 kilometers southwest of Karachi. The Indian border lies about 170 kilometers to the east. The city features numerous marketplaces and retail centers. The development of the Jamrao Canal in the early 1900s revitalized the region's agriculture, enabling the cultivation of diverse crops and contributing significantly to the local economy through the production of grains, cotton-based textiles, and sugar derived from sugarcane farms (Naeem, A. 2017).

Figure 1: Taluka Division of Mirpurkhas District Sindh Pakistan

Source: Sindh-Mirpurkhas Population Density Map - September 2014 – Pakistan

The majority of Mirpurkhas' population, particularly in rural areas, belongs to the middle and lower-income classes and continues to lead a traditional rural lifestyle. Residential structures are typically built using brick masonry, with roofs constructed from tiers and girders. Architectural features such as verandahs and courtyards remain common elements in these homes, reflecting the region's enduring vernacular building practices (Mastoi, S. T., et al, 2022).

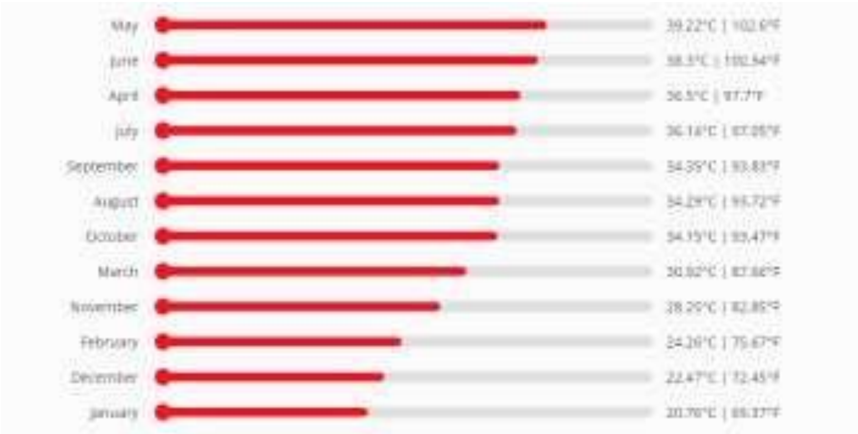
Table 1: Estimated Population of Mirpurkhas District

Taluka	Population	Male	Female	Pop Density	Average HH Size	Estimated HHs
Digri Taluka	294,321	153,050	141.271	488	5.9	49,885
Kot Ghulam Muhammad Taluka	387,778	201,649	186,129	491	5.6	69,246
Mirpurkhas Taluka	198,162	103,046	95,116	395	6.4	30,963
Sindhri	266,994	138,840	128,154	459	6.1	43,769
Jhudo	294,008	152,887	141,121	530	6.1	48,198
Hussain Bux Mari	151,718	78,895	72,823	488	6.1	24,872
Total	1,592,981	828,367	764,613	477	6	266,933

Source: Sindh-Mirpurkhas Population Density Map – September 2014 – Pakistan

A portion of the lower-income population in Mirpurkhas resides in mud-built houses or structures constructed with a combination of brick and mud. Although the city has a small industrial zone, it currently lacks fully operational industries (Sultana, S., 2019). However, it is home to four sugar mills—the oldest being Mirpurkhas Sugar Mills, followed by Mirawah Sugar Mills, Digri Sugar Mills, and Najma Sugar Mills. In addition to its agricultural significance, Mirpurkhas is also recognized for its active promotion of sports within the Sindh province (Shams, K., 2015).

Figure 2: Mirpur Khas Temperature by Month



Source: Amur, A. et.al., 2022)

Literature Review

The term *bioclimate* refers to architectural design approaches that integrate climatic and environmental factors to achieve optimal indoor thermal comfort (Kamran, M., 2020). Rather than relying solely on mechanical systems, bioclimatic architecture emphasizes design elements that naturally regulate indoor conditions, with mechanical solutions serving as supportive measures (Amur, A., 2022). A practical example of this approach is the use of natural or mixed-mode ventilation systems. A house, in this context, is defined as a structure intended for human habitation, whether for a single family or multiple occupants within one building (Yang, W., et al., 2022). Bioclimatic residential design seeks to preserve the environment through the efficient use of local materials, vegetation, and renewable energy sources. A bioclimatic house is essentially a self-sufficient dwelling that operates primarily on natural resources, minimizing dependence on mechanical systems (Peng, Y., et al., 2022).

Design Methods

In architecture, design policies serve to enhance a building's functionality and performance through thoughtful planning elements such as spatial layout, placement of openings, and variations in height. Both traditional and modern techniques contribute to these strategies. For example, cavity walls are employed to reduce heat loss by filling the air gap between layers with insulating materials. Another sustainable feature is the *green roof* or *living roof,* which involves planting vegetation over a waterproof membrane—either partially or entirely—on a building's rooftop to improve thermal performance and support biodiversity (El-Haggar et al., 2019). Additionally, wind catchers, a hallmark of traditional Persian architecture, are passive ventilation systems that facilitate natural airflow within buildings. These features are still prevalent in countries such as Afghanistan, Pakistan, and other parts of the Middle East where Persian architectural influences remain strong (Hellwig, R. T., et al., 2019).When the exterior of a building is painted with a color that reflects solar radiation, the amount of heat flux absorbed by the building is significantly reduced. This approach minimizes heat absorption while ensuring strong long-wave emission, which helps maintain a cooler interior (Khakzand, M., et al., 2023). Another architectural feature is the balcony, which is a platform extending from a building's wall, typically above the ground floor. It is supported by console brackets or columns and is often enclosed by a balustrade (Pisello, A. L., 2017).

Arch. Cettimm Gallo (1994) researches the main techniques of bioclimatic architecture. to make it simple, we must say that bioclimatic architecture is not an exclusive or new concept; it is very old indeed. This research paper portrays some of the techniques that are used in bioclimatic houses in different parts of the world (Emekci, Ş., 2021).

The materials used in construction and the way building fabrics are designed play a critical role in bioclimatic architecture. The selection of local materials and the construction methods tailored to the building's climatic requirements are key to ensuring its environmental sustainability (Naseerpour, S., 2010, October). According to B. Rivela and C. Bedoya, the atmospheric factors influencing a building's design are essential considerations in bioclimatic architecture (Lapithis, P., 2018). Edna Shaviv (2011) outlined the different stages of the design process and the tools used at each stage, noting that generative design tools are most effective in the early stages, while evaluative tools are more suitable for advanced stages, though they can also be utilized earlier (Rivela, B.). In his 2015 study, Olgyay examined bioclimatic orientation methods for buildings and highlighted that the impact of daily temperature fluctuations due to solar orientation is often overlooked (Shaviv, E., 2011). Furthermore, Vitruvius' "Ten Books" emphasizes several advantages of passive building design strategies that help minimize occupant exposure to extreme weather conditions (Kamiya, A., 2022).

Jaffe in 2016 guided the data on choosing and analyzing sites, such as latitude, sun angles, artificial and natural shade, meteorological conditions, and energy efficiency. The street layout, lot design planning of open areas, and siting for single-family detached homes and high-rise dwellings are some of the design techniques to preserve sun access. Trees, landscaping, and vegetation utilization are secondary factors for building orientation (Jaffe, T. A., 2016). Dafton G. defines the objective of energy efficiency as minimizing the quantity of energy needed to deliver goods and services. To reach and maintain a pleasant temperature, for instance, insulating a home enables a building to consume less energy for heating and cooling. By stopping heat input and loss through the building envelope, thermal insulation is a crucial technological advancement for lowering building energy usage. Low thermal conductivity building materials, frequently less than 0.1W/mK, are known as thermal insulation (Njuguna, D. G., 1996).

The widespread use of artificial heating and cooling systems has led architects to design buildings with glass facades; however, this approach should not dominate architectural design. Architecture should not be dictated by these systems. This principle was effectively demonstrated by Le Corbusier, who meticulously studied climatic conditions before designing any building. Other examples of bioclimatic techniques incorporated into residential design include greenhouse verandahs, solar chimney walls, thermal mass walls, and sun ducts, all of which work to optimize natural climate control (Leslie, T., 2018).

Research Summary

In bioclimatic architecture and energy-efficient building design, a variety of passive and active strategies are employed to create sustainable and comfortable living environments. These strategies include the use of underground wind catchers to regulate temperatures, particularly in hot Mediterranean climates, and passive solutions such as ventilation, dehumidification, and shading in hot and humid regions (Aghimien, E. I., et al., 2022). Key elements of bioclimatic design also involve green roofs, glazed surfaces, natural ventilation ducts, and the strategic orientation of spaces to maximize natural light while minimizing energy use (Xhexhi, K., 2023). Additionally, water recycling, the selection of appropriate construction materials, and considerations for outdoor thermal comfort are essential components. By integrating natural principles and technologies like solar arrays and thermal collectors, bioclimatic architecture reduces pollution, lowers costs, and decreases energy consumption (Aghamolaei, R., et al., 2023). In hot and arid regions, patio houses constructed with light-insulating materials and natural features help mitigate excessive heat. Collectively, these strategies contribute to sustainable, cost-effective, and environmentally friendly building designs (He, Z. H., 2021).

This research aims to develop design strategies for the Bioclimatic House by adopting passive design techniques, eco-friendly materials, solar systems, and organic waste.

Research Method

The first step in the research was to identify the several issues that the community of Mirpurkhas, Sindh, Pakistan, was facing, including discomfort from the heat, unhygienic living conditions, high energy costs, etc. Thus, research covered a variety of Pakistani topics about the energy crisis and difficulties with thermal discomfort in residential buildings, particularly in rural areas. To improve thermal comfort in residential structures, this research addresses several strategies for varying seasons. A rural region of Pakistan's Mirpurkhas is chosen for this study. More information about the rural area's housing and living circumstances, energy crisis, etc., is investigated. A community-based questionnaire survey is used to investigate the issues facing rural communities. The study makes several recommendations for passive design strategies that are applied to building orientation. To increase comfort and decrease pollution, some energy-efficient measures are also recommended. These include wind catchers, which provide cold air to covered spaces, vegetation, which filters air, and windows and their shading devices that are measured properly in terms of size, shape, placement, and projections.

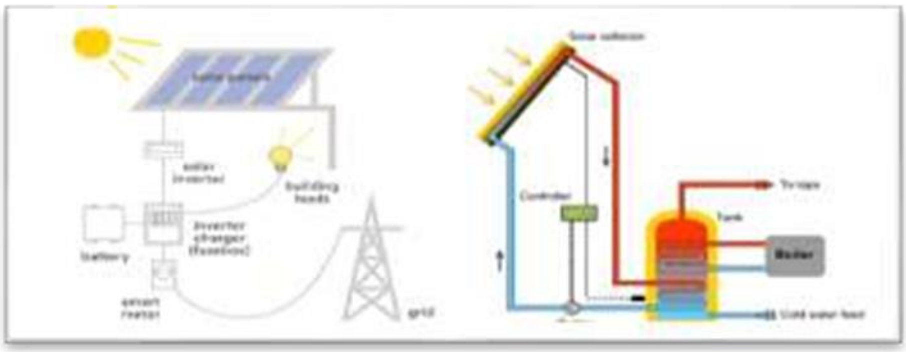
Design Strategies and Discussions

During a long time of investigation, investigations, and surveys, several issues were looked at regarding the rural Mirpurkhas area, including environmental pollution, lack of gas supply, discomfort from the heat, and energy shortages. This study offers several effective and feasible remedies, such as:

Sunlight for Electricity in the House

One of Earth's life support systems, the sun provides both light and heat. Every 50 minutes, solar energy, which is clean, abundant, and renewable, provides enough energy to cover the world's annual consumption needs. Gathering even a tiny portion of this radiant energy and heat is the challenge.

Figure 3: Solar System for Electricity



Source: www.leonics.com

Although off-grid domestic solar power systems are cut off from the typical electric power grid, grid-tied solar power systems are directly connected to both the home and the traditional electric utility grid. Batteries allow periods of surplus production and demand to be balanced when there is no connection to the electric grid (Ramesh, S., 2016).

Sunlight for Water Treatment in the House

Solar water heating is a technique that uses solar radiation to heat water in a panel that is often mounted on the roof. The heated water can then be used as hot water or to power a central heating system. Solar panels can be installed on a flat roof or an angled frame on the ground. They should be positioned on a south-facing pitched roof that is free of shadow and has a pitch of between 20 and 50 degrees. A roof area of two to five square meters is needed for a normal domestic installation. If an additional water cylinder is needed, you may also need space for it (Ratnani, P., & Joshi, K., 2021).

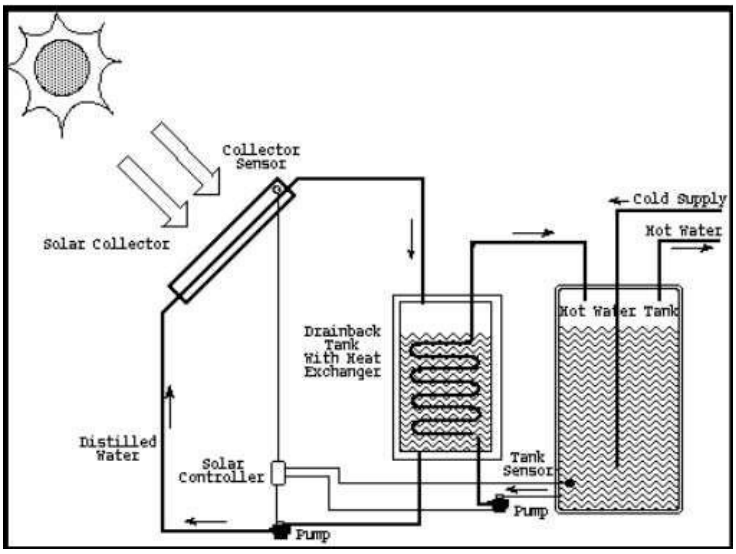
Solar System for Water Heating

Using a solar thermal collector, solar water heating (SWH) is the process of converting solar radiation into renewable energy for water heating. Systems for solar water heating include a variety of methods that are being used more and more globally. The storage tank of a "close-coupled" SWH system is positioned horizontally, directly above the roof's solar collectors. Since the hot water climbs into the tank naturally due to thermosiphon flow, no pumping is necessary (Saha, T., 2023). A circulating pump transfers water or heat transfer fluid between the storage tank and the collectors in a "pump-circulated" system, which has a ground- or floor-mounted storage tank below the level of the collectors.

Solar System for Water Purification

A solar water purification system is a home water purification system that uses solar heating in addition to water distillation and treatment of solar radiation. In situations where low turbidity water is not accessible, non-volatile solid contaminants such as salts, silt, heavy metals, and microbes will be eliminated from polluted water by distilling it using a solar-heated still to produce potable water. Even if the water in some wells and rivulets appears pure, it might not be safe to drink (Al-Mamun, 2023). The polluted water would be contained in a clean to address this issue. The solar energy collector, the solar distillation system, and the solar water disinfection system are the three primary parts of the system. A device called a solar energy collector gathers solar radiation and transforms it into thermal energy for use in the solar distillation process and the SODIS. As seen in Figure 4, the solar distillation system is comparable to the traditional water distillation system. Using sun radiation, a solar water disinfection system purifies low turbidity, microbiologically polluted water into potable water. All three systems are connected by an insulated or thermally resistant piping system, which should be as short as feasible to reduce heat losses (Li, Q., et al, 2019)

Figure 4: Solar Water Heating System and Water Purification



Source: energy.gov

Organic Matter

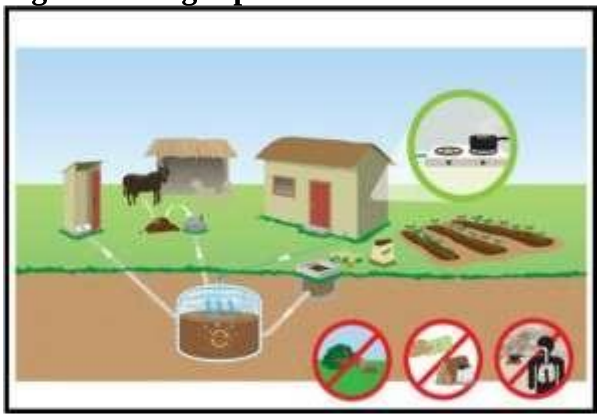
Farm animal waste comes from livestock, poultry, and dairy production. It can be manure from farm animals or the byproducts of meat processing. It has been used as fertilizer in the old times but now its utilization has become more evaluated, now a day it is widely used in the biomass process for biogas. Primarily talk about biogas refers to a mixture of several gases (Table 2) that are created when organic matter breaks down in the absence of oxygen. Biogas can be generated from a variety of raw sources, including green waste, food waste, sewage, plant material, manure, and agricultural waste (Dikgale, K., 2019).

Table 2: Typical composition of biogas

Compound	**Formula**	**%**
Methane	CH_4	50-75
Carbon Dioxide	CO_2	25-50
Nitrogen	N_2	0-10
Hydrogen	H_2	0-1
Hydrogen sulfide	H_2S	0-3
Oxygen	O_2	0-0.5

Since it generates no net carbon dioxide and has a continuous cycle of production and use, biogas is regarded as a renewable resource. The cycle of organic material growth, conversion, and consumption, followed by regeneration, is continuously repeated (Figure 5). In terms of carbon, the primary bioresource grows with the absorption of as much atmospheric carbon dioxide as it releases during the final conversion of the material into energy (Lam, C.K. et al, 2023).

Figure 5: Biogas process

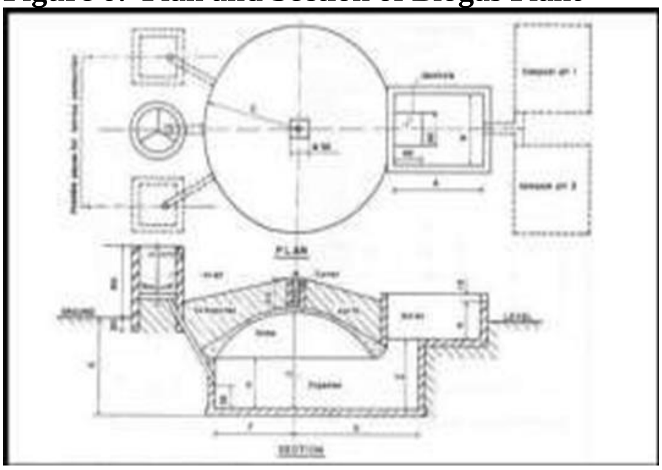


Source: practicalaction.org

Use of biogas in-house

Once the biogas is made, we can use it in two ways in a single house (shown in Figure 6). Biogas is mainly used for cooking gas (methane gas) and another use is to run generators for electricity. But its pressure is not high that is why only light electric appliances can run on this generator.

Figure 6: Plan and Section of Biogas Plant



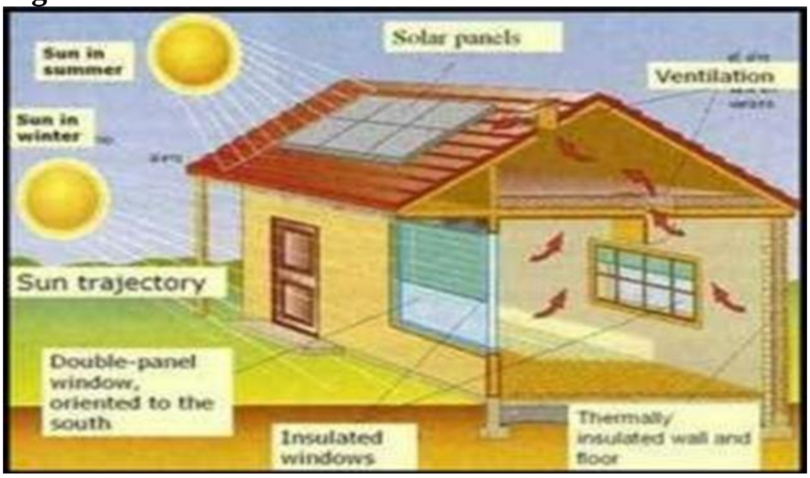
Source: www.nathmotors.com

Architectural Factors of Bioclimatic Building Orientation of Building

Orientation is the main and basic factor of any building. It is the art of placing a building concerning a particular direction. As a result of avoiding the cost of heating and cooling, a properly oriented structure can save you a significant amount of money because it keeps you comfortable without incurring many extra expenses. There are two main points for orienting any building (Vaishnav, S., 2023).

Orienting the building to make use of the Sun. Figure 7 illustrates how we may design and build structures that reject heat in the summer and capture free heat in the winter, since the sun is lower in the sky in the winter than it is in the summer.

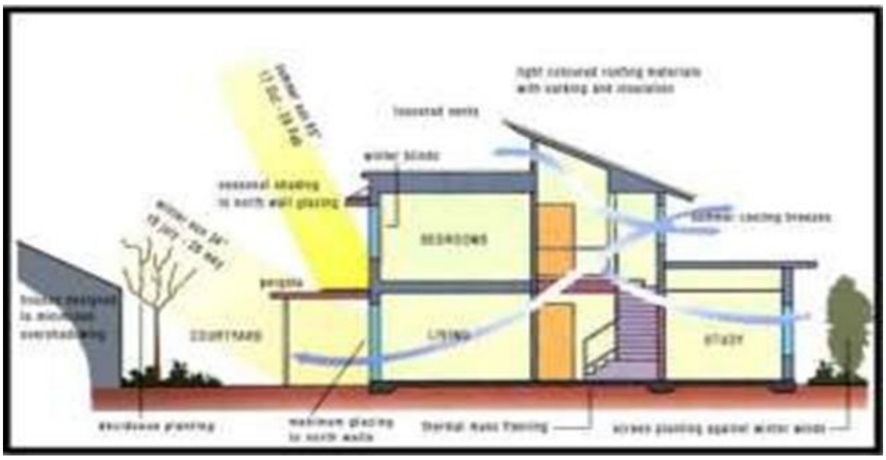
Figure 7: Orientation W.R.T Sun



Source: blog.smartgardener.com

Using the wind to your advantage when you orientate your building, the maximum advantage of wind we can get by ventilation or cross ventilation. When placing ventilation openings, you are placing inlets and outlets to optimize the path air follows through the building. Windows or vents placed on opposite sides of the building give natural breezes a pathway through the structure (Priyadharsini, P., et al, 2022).

Figure 8: Orientation W.R.T Wind



Source: wordpress.com

Shading Device

Devices designed specifically to shield from sunshine, and natural light, or to block views are known as shading devices. Horizontal shading devices, which are positioned in front of windows in a variety of ways, and vertical shading devices, which are located inside buildings and can be either fixed or movable, are the two main categories of shading devices. Additionally, vertical shade devices can be made with different angles depending on where the sun is (Sinha, A. 2020).

Figure 9: Horizontal Shading Shading Device

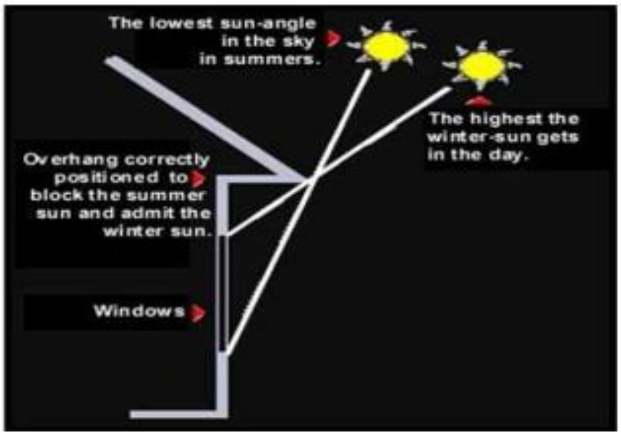
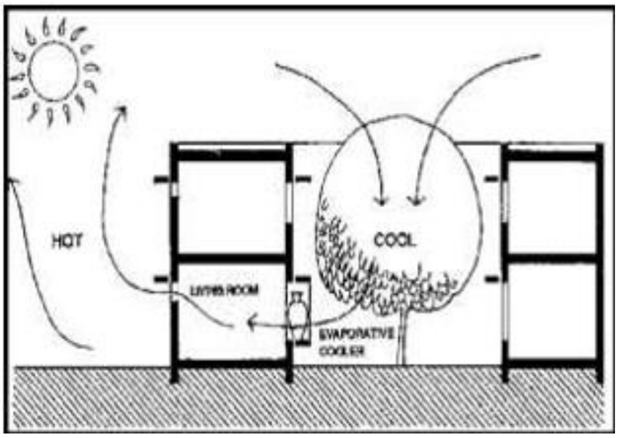


Figure 10: Air Filtration Through Natural



Source: www.revitcity.com

In devices that naturally shade, as seen in Figure 9, shade can be provided periodically when trees and other plants are present. In addition to providing shade, vegetation can also reduce wind, precipitation, and solar radiation. Well-planted trees can reduce a building's energy use by up to 30% (see Figure 10) (Ansarimanesh, M., 2019).

Conclusion

The implementation of bioclimatic design techniques in rural homes in Mirpurkhas represents a promising strategy to address the unique challenges faced by the region. By incorporating locally-sourced materials, utilizing natural ventilation, and optimizing building orientation, bioclimatic architecture can significantly reduce energy consumption, lower costs, and enhance the comfort of rural homes. These techniques not only provide an environmentally sustainable solution but also align with the cultural and climatic context of Mirpurkhas, making them a feasible choice for rural communities. Moreover, such an approach would contribute to reducing the region's carbon footprint and environmental degradation while fostering self-sufficiency in energy use. The widespread adoption of bioclimatic housing can lead to improved living standards, increased resilience to climate change, and a better overall quality of life for rural populations. Ultimately, this approach offers a holistic solution that combines sustainability, economic viability, and cultural relevance, addressing both immediate needs and long-term objectives for the region's development.

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