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Sustainable and Energy-Efficient Building Design for Soldiers' Accommodation in Pakistan

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Abstract

In hot, arid regions like Jacobabad, Pakistan, military barracks must be sustainable and energy-efficient. This study investigates architectural techniques to improve energy efficiency while maintaining the comfort of military soldiers. The research is guided by a systematic process that includes experimental design, climate assessment, case study analysis, and energy performance modelling. Case studies and climate analyses are crucial elements in detecting environmental issues like excessive heat and sun radiation. The Hourly Analysis Program (HAP) and Building Information Modeling (BIM) are used in energy performance modelling to assess the effects of ventilation, shading, insulation, and orientation. Materials, window locations, and shading strategies are evaluated using a design of experiments (DOE) framework. The integration of renewable energy sources, especially solar photovoltaic panels, and passive cooling techniques are given top priority in this study. Practicality is ensured by validation and optimization, which results in a framework for military accommodations that use less energy and are more sustainable in harsh environments.

Keywords: *barrack; design strategy; energy efficient buildings; sustainable buildings*

Introduction

Rapid urbanization, population growth, and technological improvements are all contributing to the steady rise in the world's energy demand. Serious energy problems have resulted due to these issues, especially in developing countries like Pakistan.A precarious energy situation and a lack of domestic resources have made a significant reliance on expensive energy imports in Pakistan. In this regard, creating environmentally friendly and energy-efficient buildings has become a vital way to mitigate energy crises, cut expenses, and lessen their effects on the environment.

The city of Jacobabad in Pakistan's Sindh region, which frequently has summer temperatures above 50°C, is a prime example of the terrible reality of extreme climates. Because of the greater need for artificial cooling to ensure indoor thermal comfort, buildings in these areas use a lot of energy. However, energy efficiency is overlooked in traditional construction methods, which results in excessive energy use and increased operating expenses. In addition to having high energy requirements, the current residential barracks for soldiers in Jacobabad do not provide enough comfort for its residents. To maximize energy use, improve tenant comfort, and lessen environmental effects, these issues must be resolved.

The following goals are made to combat these issues through the present study;

1. To use cutting-edge methods like the Hourly Analysis Program (HAP) and Building Information Modeling (BIM) to assess the energy performance of a barrack building in Jacobabad.
2. To determine and put into practice energy-efficient design techniques suited to Jacobabad's hot environment.
3. To incorporate sustainable design elements, such as enhanced insulation, passive cooling strategies, and renewable energy systems, in order to lower the building's overall energy use.
4. To provide a measurable framework for designing energy-efficient buildings in harsh climates that tackles both financial and environmental issues.

This project is interesting because it takes a comprehensive approach to building energy-efficient barracks in one of the hottest regions on earth. This work integrates material analysis, creative design techniques, and useful modeling tools, in contrast to traditional studies that mostly concentrate on theoretical frameworks. The findings' relevance and applicability are ensured by the focus on localized solutions, such as employing renewable energy sources, passive solar design, and locally produced materials with low heat conductivity. This study is a pioneer in the field of energy-efficient building research for military accommodations since it also uses the Design of Experiments (DoE) technique, which provides a methodical way to optimize building performance by changing important input factors.

Literature Review

Energy-efficient barracks are essential in hot regions like Jacobabad, Pakistan, where summer temperatures can reach 50°C. In addition to providing comfort for the occupants, a well-planned barrack reduces energy consumption and operating costs(Kugelman, 2016). Artificial cooling can be significantly reduced through passive design measures like strategic window placement, insulation, and shading. Energy-efficient appliances and lighting fixtures can also reduce energy consumption(Mardookhy et al., 2014). Solar panels can also provide clean and sustainable energy, reducing reliance on the grid (Peruzzi et al., 2014). Local materials and building techniques should also be considered for minimal carbon footprints and local economic support. An energy-efficient barrack can provide occupants with a comfortable and sustainable living environment while saving energy consumption and costs(Mardookhy et al., 2014).

Energy-efficient buildings reduce energy losses, such as heat loss through their envelopes, by constructing or upgrading buildings that use energy efficiency(Zarrella et al., 2020). Energy-efficient buildings must take the climate into account first. In the past, when mechanical systems and electricity were not available, buildings were built with the local environment in mind. This was to provide maximum comfort for the occupants. Electricity-enabled lighting, heating, ventilation, and air conditioning systems. This allows a building to remain within a thermal comfort zone without considering the local climate. However, buildings designed without climate consideration will likely consume more energy to maintain suitable resident conditions(Peruzzi et al., 2014).

Weather-dependent and non-weather-dependent weights for buildings can be distinguished(Lazos et al., 2014). Appliances and lighting are a couple of examples of non-weather-based loads. Improving efficiency is the primary objective in order to reduce non-weather-dependent loads. This type of load can also be decreased by reducing the working time. For example, occupancy sensors can be used to turn off equipment after a set period of inactivity, and illuminance sensors can lower lighting levels during daylight hours. Cooling/heating and water heating are two examples of weather-dependent burdens(Zarrella et al., 2020).

This form of load reduction is more complicated and calls for various approaches in various climate zones. Utilizing a well-insulated and compact building envelope, using passive solar heat gain, and recovering heat from exhaust air are all methods for lowering room heating loads. Preventing summer solar heat gain through openings, preventing heat transfer into the building through a well-insulated and tight building envelope, and using additional precooling strategies like night ventilation and floor ventilation are ways to reduce the cooling burden. In order to cut down on load hours in heating and cooling systems, automatic operation modification, shutdown, and temperature setbacks are used. Strategies to lower demand for hot water systems include using solar energy, low-flow fixtures, and improving system performance(Efficiency, 2018).

1. Energy Efficiency in Residential Buildings

In the modern world, the energy efficiency of residential structures is becoming increasingly crucial. Residential buildings use a sizeable percentage of the world's energy consumption. Buildings are responsible for about 30% of global energy usage and 28% of global carbon dioxide emissions, according to the International Energy Agency (IEA). For a sustainable future, it is crucial to concentrate on increasing the energy efficiency of residential structures(Strakos et al., 2016).

Building design is one of the best methods to increase the energy efficiency of residential buildings. For instance, structures should be planned to enable natural light to enter and move throughout the structure. This helps save energy by lowering the need for artificial illumination. Additionally, natural ventilation should be encouraged in structures so that less air conditioning is required(Zarrella et al., 2020).

Utilizing energy-efficient appliances is another method to increase the energy efficiency of residential buildings. Old, inefficient equipment can be swapped out for new, energy-efficient ones by homeowners, which can help save on energy costs. For instance, Energy Star-certified appliances are made to be more energy-efficient than conventional appliances and can reduce residents' energy costs by up to 30% (Feng et al., 2019).

Insulation is a crucial component in increasing the energy efficiency of residential structures. Proper insulation can lessen the need for heating during the cold by preventing heat loss. In a similar vein, it can lessen the need for air cooling during the summer by assisting in preventing heat gain. Homeowners can add insulation to walls, floors, and attics to increase energy effectiveness (Peruzzi et al., 2014).

Residential structures are also embracing innovative house technology more and more. For example, intelligent devices can heat homes more effectively and coolly. These thermostats can determine the homeowner's routine and adjust the temperature appropriately. Homeowners can also watch their energy use with innovative house technology, allowing them to pinpoint areas where their energy efficiency could be increased(Mardookhy et al., 2014).

In conclusion, increasing domestic structures' energy efficiency is essential for a sustainable future. The energy economy of residential structures can be increased in several ways, including building architecture, insulation, energy-efficient appliances, and smart home technology. Homeowners can lower their energy use and their electric costs and contribute to a more sustainable future by implementing these and other energy-efficient practices.

2. Barrack

Barrack design is essential to military planning and providing accommodation for service personnel. The design of barracks must consider the unique needs of military personnel, including their safety, comfort, and privacy(Goltz & Turek, 2017).

Goltz and Turek (2017) further explained that one of the most critical aspects of barrack design is to provide adequate space. The space should be sufficient to accommodate the personnel assigned to the barracks comfortably. The sleeping areas should provide reasonable privacy and incorporate measures to enhance sleep quality, such as soundproofing and blackout curtains.Barracks should also be designed to promote military personnel's physical and mental well-being. This means ensuring that the barracks are adequately ventilated and provide access to natural light. Facilities for physical exercise and sports should also be incorporated into the design to promote good health and fitness.

In addition to the physical aspects of barrack design, security is also a critical consideration. Barracks should be designed to ensure the safety of military personnel and their possessions. This may include providing secure storage areas for personal belongings and security measures such as CCTV, access controls, and alarms(Ellis & Herron, 2012).

Another essential aspect of barrack design is the provision of communal areas. Common spaces such as dining halls, recreation rooms, and study areas should be provided to foster a sense of community among military personnel. To promote their use, these spaces should be comfortable, functional, and well-maintained(Ellis & Herron, 2012). Finally, barrack design should consider the potential for future expansion or modification. Military operations constantly evolve, and barracks design should be flexible enough to accommodate changing requirements. This may include providing modular or flexible spaces that can be easily reconfigured to meet changing needs.

In conclusion, barrack design is a critical aspect of military planning, and the provision of adequate and appropriate accommodation for military personnel is essential for their well-being and effectiveness. Barracks should provide sufficient space, comfort, and privacy while promoting physical and mental well-being and security. The provision of communal spaces and flexibility for future expansion or modification is also essential.

This is a typical building where the soldiers live, observing the recent climatic changes and overall temperature in all country regions. We are focused on Jacobabad city for the barrack energy analysis as the area is considered one of the extremely hot regions of the country.

After analysis of the different climatic design parameters, we can build a unique design parameter for hot areas. We can reduce the energy requirement by 25 to 30% through these parameters.

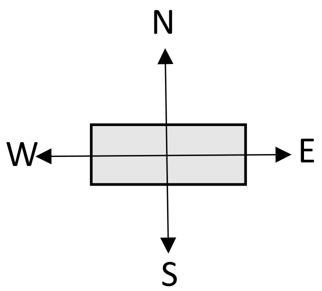
3. Climatic Condition of Jacobabad

Jacobabad is located in southern Pakistan, in the Sindh province, in the Indus Valley, at 28 degrees north latitude. The climate of Jacobabad is a subtropical desert, with a very mild winter, an extremely hot period from April to June, and a period from July to September partially affected by the Indian monsoon(Khalil & Zaheer, 2013). According to Amnesty International, Jacobabad has consistently been facing sweltering heat in the summer months since 2017, and the city has been labelled “unlivable for humans” due to the extreme heat. Jacobabad may have recently crossed a temperature threshold too severe for human tolerance, regularly surpassing 50°C in the summer months and reaching temperatures of 52 °C, which could potentially be fatal to human beings(Ali et al., 2021).

4. Design Parameters

These parameters help us to reduce the temperature by at least 10 to 12 degrees. The parameter is further categorized into the following points(DeKay & Brown, 2013).

Tabel 1. Design Parameters For Climate-Responsive Architecture (Hot Area)

Design Parameters For Climate-Responsive Architecture (Hot Area)	
Orientation/Layout	Building a longer Axis facing the N-S direction 

Air circulation/Ventilation	To reduce solar gain and for adequate ventilation, any of the following elements or combinations may be applied (a) Provision of ventilators (b) Provision of skylights (c) Courtyard planning (d) Deep verandahs
Construction Material	1. Bricks (burnt &flyash) 2. PCC solid blocks 3. PCC hollow blocks 4. CLC blocks
Top Roof	1. Flat roof. 2. Provision of any roof insulation specified in Note 1 below to reduce heat gain through conduction
Building Walls	1. Provision of insulated walls is not required in normal climatic areas. 2. Light colours on external walls to 3. Maximize solar reflection.
Recommended Ceiling height	12ft-15ft
Window design	1. Windows facing North and East orientation for indirect sunlight 2. Single-glazed operable windows 3. Horizontal and vertical louvres in the southern and southwest faces must allow the sun inside during the winter.
Vegetation/Landscaping	Deciduous trees (Maple, Peepal, Darekh, Amaltas, Jacaranda) or indigenous trees that shed leaves in winter to be planted for uninterrupted solar radiation in the fall and shade in summer.
Design for Sustainability	1. Grey Water Treatment - reuse for flushing and gardening. 2. Rain Water Harvesting - reuse of treated water for all purposes, including recharging of UGWT. 3. Use of solar and biomass to generate energy. 4. Use local materials and passive design techniques for energy-efficient buildings.

Source: Author

Designing a barrack for hot regions requires careful consideration of several parameters to ensure that it is functional, comfortable, and energy-efficient. Here are some design parameters to consider (Ahmad et al., 2021).

Orientation: The barrack should be oriented to minimize the direct sunlight entering the building. This can be achieved by positioning the building with its long axis in an east-west direction.

Ventilation: Hot regions require effective natural ventilation systems to provide fresh air and remove hot, stale air. The barrack should have windows, louvres, or other openings for cross ventilation.

Insulation: The barrack should be well insulated to reduce solar heat gain and keep the interior cool. This can be achieved using highly insulated materials, such as reflective roofing materials, or by creating a double-skin facade.

Shading: The building should be designed with adequate shading to protect the interior from direct sunlight. This can be achieved using overhanging eaves, shading devices, or planting trees or shrubs.

Thermal Mass: High thermal mass building materials, such as masonry, concrete, or adobe, should be used in the design of the barrack. By absorbing heat during the day and releasing it at night, these materials can assist in controlling the building's interior temperature.

Lighting: The barrack should be designed with ample natural lighting to reduce the need for artificial lighting. This can be achieved using skylights, clerestory windows, or other daylighting strategies.

Water Efficiency: Hot regions often experience water shortages, so the barrack should be designed with water-efficient fixtures and systems, such as low-flow toilets, showers, and rainwater harvesting systems.

Energy Efficiency: The barrack should be designed to minimize energy consumption. This can be achieved by using energy-efficient appliances, lighting, and HVAC systems and incorporating renewable energy sources, such as solar panels.

Durability: The barrack should be designed to withstand the harsh conditions of hot regions, such as high temperatures, strong winds, and sandstorms. This can be achieved using durable materials and construction techniques, such as reinforced concrete and steel framing.

Cost: The design should be cost-effective and within budget while meeting functionality, comfort, and energy efficiency requirements. This can be achieved by using inexpensive materials and construction techniques and optimizing the design to minimize waste and reduce construction time.

5. Role Of Trees and Plantation in Hot Area Energy-Efficient Building

Trees and plantations can make buildings in hot areas more energy-efficient. Here are some ways in which trees and plantations can help(Xiong et al., 2019):

Shading: A building's exposure to direct sunlight can be decreased by the natural shading that trees and plantations can provide. This can lessen the need for air conditioning and keep the facility cooler.

Evapotranspiration: Trees and plantations can help to cool the surrounding air through a process called evapotranspiration, which involves the release of water vapour from leaves. This can help to reduce the ambient temperature and make it more comfortable for people inside the building.

Windbreaks: Trees and plantations can also act as windbreaks, which can help to reduce the wind speed and turbulence around a building. This can help to prevent heat loss through convection and reduce the need for heating.

Carbon Sequestration: Carbon dioxide is taken up from the atmosphere and stored in the tissues of trees and plants. This can enhance air quality and lessen the building's carbon footprint.

Aesthetic Value: Trees and plantations can also enhance the aesthetic value of the building and create a more pleasant environment for people to live or work in.

It is essential to choose the right type of trees and plantations for the hot area's specific climate and soil conditions. Trees and plantations can be strategically placed around the building for maximum shading and wind protection. Proper maintenance and care should also ensure that the trees and plantations remain healthy and provide the desired benefits.

Methodology

This study uses a methodical approach to evaluate, plan, and maximize the energy efficiency of a barrack with 128 soldiers situated in the hot and humid region of Jacobabad, Pakistan. The following crucial steps are part of the methodology that took place one by one.

1. Case Study And Data Collection

In order to reflect typical residential constructions in hot climates, the barrack building was chosen as a case study at the beginning of the project. The following methods are used to gather pertinent information on the building's architectural design, materials, occupants, and energy usage patterns:

- Field surveys: Visits to the location to record the materials, orientation, and thermal insulation characteristics of a building.
- Historical Records: To help guide design choices, local climatic data, such as temperature profiles, sun radiation, and wind patterns, are analyzed.
- Examining construction designs, specifications, and operational information is known as building documentation.

2. Climate Analysis

To comprehend the unique difficulties presented by Jacobabad's subtropical desert climate, a thorough climatic investigation is carried out. The analysis consists of:

- Temperature fluctuations by day and season.
- The intensity of solar heat uptake on building surfaces increases.
- Patterns of the wind for opportunities for natural ventilation.

To lessen the heat stress in the area, the results inform the choice of passive and active design techniques.

3. Energy Performance Modeling

Using sophisticated computational techniques, building energy efficiency is simulated in order to assess both suggested and current design strategies:

- Using Autodesk Revit, a 3D model of the barrack's geometry, materials, and HVAC systems is produced as part of Building Information Modelling (BIM).
- HAP, or the Hourly Analysis Program: For various design scenarios, energy simulations are used to determine cooling loads, thermal comfort levels, and energy consumption.
- Energy consumption, cooling loads, and indoor temperature profiles are among the key performance indicators (KPIs) that are examined.

4. Design Of Experiments (DOE)

The effect of several variables on energy performance is methodically evaluated using a Design of Experiments (DoE) framework. Among the variables are:

- Insulating materials for walls and roofs with different levels of heat conductivity.
- Window location and building orientation.
- Application of reflecting surface coatings and shading devices.
- To determine the best design configurations, simulations are run for various combinations of these factors.

5. Passive Design Strategies

In order to reduce energy usage, the study gives priority to passive cooling methods, including:

- Shading: To lessen direct sun gain, use vertical louvres, overhangs, and deep verandas.
- Natural Ventilation: Improving cross-ventilation by strategically placing and sizing windows.
- Insulation: Presenting superior wall and roof insulation materials.

6. Renewable Energy Integration

To counteract energy usage, renewable energy technologies are incorporated into the design, such as solar photovoltaic (PV) panels. The energy needs and local sun irradiation are used to assess the viability of these systems.

7. Result Validation and Optimization

By contrasting the simulation results with actual energy data from nearby buildings that are comparable, the results are verified. Sensitivity analysis is used to determine how important design parameters affect energy efficiency. Iterative optimizations are used to guarantee practicality and cost-effectiveness.

8. Development Of A Framework

A reproducible framework for designing energy-efficient buildings in harsh climates is created based on the results. This framework provides guidance for the next initiatives in comparable areas by outlining best practices, suggested materials, and design tactics.

Result and Discussion

1. Result

Table 2. Energy-Efficient Design For Barracks In Hot Climates Table

	Baseline	Optimized Design	Improvement
Cooling Load	24 kWh/m²/month	13 kWh/m²/month	46% reduction
Indoor Temperature	Frequently >35°C	Maintained at 24–28°C	Significant thermal comfort improvement
Building Orientation	Long axis facing north-south	Long axis facing east-west	Reduced solar heat gain by 15%
Shading	None	Deep verandas, overhangs, louvres	Reduced solar heat gain by 18%
Insulation	Standard construction materials	High-performance insulation	Reduced cooling load by 22%
Renewable Energy Contribution	No renewable energy	Solar PV panels providing 40% energy	Reduced grid dependency and operational costs
Material Costs	Dependent on imported materials	Locally sourced materials	12% cost savings
Energy Savings	High energy demand	46% reduction in energy consumption	Significant cost reduction
Payback Period	Not applicable	6 years (solar PV system)	Feasible long-term investment

Source: Author

Cooling Load And Shadow Analysis

Cooling load analysis for existing building structure, occupancy, lighting, equipment and infiltration load was fixed, while the Design of Experiments DOEs was by varying building material, insulation and orientation of the building(Salameh et al., 2020).

The maximum cooling load was attained with a wall assembly comprising 9" brick masonry, a 6" thick roof slab, with all sides exposed to the sun, and a long axis of the building facing east. With the same configuration, the orientation of the building was changed with a longer axis facing south;a subsequent drop in the cooling load was observed.

Detailed scrutiny of the cooling load results for the later configuration shows that the West side received maximum Solar Heat Gain (SHG), followed by the East and North sides with the minimum solar influx. From these results, it can be inferred that on the East and West sides, non-loving spaces, such as lavatory blocks, stores, etc., can be added to curtail solar irradiation to attain thermal comfort for inhabitants(Hendron et al., 2013).

Shadow and cooling load simulations were carried out to ascertain the effect of verandas on Solar Heat Gain from walls on the South-North side where maximum doors and window openings exist. The results show that including verandas will curb the solar impact in summer and assist in getting maximum sunlight in winter due to the low sun trajectory.

Sun Path South and West Face Analysis

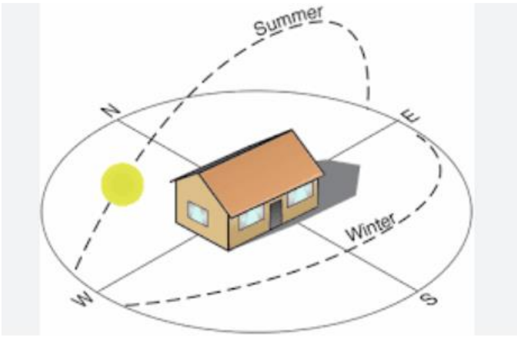


Figure 1. Building Orientation for Optimum Energy
Source: Fallahtafti and Mahdavinejad 2015

The impact of insulation on cooling load was assessed using locally available insulating materials (such as XPS boards, EPS Panels, Polyisocyanurate boards, etc.) in Pakistan. Results show that the maximum solar heat influx is through the rooftop.

Impact Of Different Architectural Techniques To Reduce The Cooling Load

The cooling burden of buildings in hot climates can be decreased by using a variety of architectural strategies. These methods can enhance home comfort while lowering carbon emissions and energy use. These are some of the most successful methods(Salameh et al., 2020):

1. Passive Solar Design: This method heats and cools a structure by harnessing the energy of the sun. The building can be oriented to optimize winter solar gain and minimize summer solar gain in order to do this. Additional tactics include the use of thermal mass to absorb and retain heat, shading devices, and high-performance windows.
2. Natural Ventilation: Natural ventilation is a cost-effective way to cool buildings in hot areas. This involves using windows, doors, and other openings to allow fresh air to circulate through the building. Natural ventilation can be enhanced by using wind catchers, ventilation shafts, and other passive cooling techniques(Xiong et al., 2019).
3. Green Roofs: Roofs with plants covering them are known as green roofs. By offering insulation and absorbing solar radiation, they can lessen the cooling strain on buildings. Additionally, green roofs can enhance air quality and lessen stormwater runoff(Wong, 2017).
4. Insulation: An integral part of every energy-efficient structure is insulation. Heat loss in the winter and heat gain in the summer are lessened by it. Materials like foam board, fibreglass, and cellulose can be used to create insulation.

5. High-performance Windows: Designed to minimize heat transmission and increase energy efficiency, high-performance windows can be constructed with many panes, gas fills to lower the U-factor and the solar heat gain coefficient, and Low-E coatings(Salameh et al., 2020).
6. Reflective Surfaces: Reflective surfaces such as cool roofs, walls, and pavements can help reduce the amount of solar radiation absorbed by a building. This can help to reduce the cooling load and improve indoor comfort.
7. Efficient Lighting: Efficient lighting can help reduce buildings' cooling load by reducing the heat generated by light fixtures. This can be achieved by using LED lights, which are more energy-efficient than traditional incandescent bulbs(Wong, 2017).

Overall, these architectural techniques can be combined to reduce the cooling load of buildings in hot areas. Reducing energy consumption and improving indoor comfort can help create sustainable, efficient buildings that are better for the environment and the people who live or work in them.

Solar radiation is the primary source of heat gain in buildings in hot areas. Solar radiation refers to the energy that is transmitted from the sun in the form of electromagnetic waves. When solar radiation strikes a building, it is absorbed by the roof, walls, and windows, which can cause the temperature inside the building to rise.

Other sources of heat gain in buildings include:

The primary source of heat gain in buildings in hot areas(Harlan et al., 2014):

1. Heat transfer through conduction: Heat can be transferred from hot surfaces to more excellent surfaces. For example, heat can be conducted from a hot roof to the ceiling of a building.
2. Heat transfer through convection: Heat can be transferred through air movement. In hot areas, warm air rises and cool air sinks, which can create convective currents that transfer heat from the roof to the interior of the building.
3. The heat generated by equipment and people: Equipment such as computers, lights, and appliances can generate heat that can contribute to the overall heat load of a building. Similarly, the presence of people in a building can also generate heat.
4. Infiltration of outside air: In hot areas, outside air can be hot and humid, and when it infiltrates into a building, it can increase the temperature and humidity levels inside the building.

To reduce heat gain in buildings, it is essential to implement strategies such as insulation, shading, ventilation, and reflective surfaces. These strategies can help to reduce the amount of solar radiation that is absorbed by the building, as well as the amount of heat that is transferred through conduction, convection, and infiltration.

2. Discussion

In hot and arid areas like Pakistan, an energy-efficient barracks design can have a big influence on the military's energy usage and carbon footprint. This study investigates different design elements and architectural strategies that can improve energy efficiency while maintaining military personnel's comfort.

Reducing excessive heat intake while preserving a comfortable indoor environment is crucial in hot and dry areas. In order to do this, building mass and materials are essential. Materials with a high thermal mass, such as concrete, adobe, or rammed earth, can collect heat during the day and release it at night, minimizing temperature swings (Givoni, 1994). Traditional desert architecture frequently uses thick walls to reduce heat transfer and keep the interior temperature steady (Olgyay, 1963). These features support the idea that thick walls and compact mass work well in hot, dry climates, while elongated forms are better suited to other types of climates (Koenigsberger et al., 1974). These theories suggest that high thermal mass compact designs offer passive heating and cooling advantages appropriate for Pakistan's hot, dry environment, where there is a considerable day-to-night temperature difference. On the other hand, in humid or tropical conditions, where air circulation is essential to reducing high moisture levels, elongated forms and extensive cross-ventilation schemes work well.

Energy efficiency is also influenced by the barracks' orientation. Solar gain can be maximized in the winter and minimized in the summer with proper orientation. To lessen direct solar exposure on the longer walls, the east-west axis is usually the preferable orientation in hot and dry climes. This method enhances thermal comfort and lessens overheating (Szokolay, 2004). Given that extended exposure to strong sunlight might result in higher cooling requirements, this design strategy is essential for Pakistan's military housing.

In warmer areas, insulation is still crucial since it limits heat loss at night and prevents excessive heat gain during the day. The thermal efficiency of the building envelope can be considerably increased by using high-performance insulation materials such as foam boards, fibreglass, and cellulose (Evans et al., 2017).

Another important aspect of the design is shading devices. Awnings, canopies, and louvres are examples of external shading devices that can lower solar heat gain and enhance indoor comfort. Direct sunlight is reduced during peak hours by carefully positioning these shading devices on the east, west, and south-facing sides. By serving as insulation, absorbing solar radiation, and lowering overall heat buildup, green roofs can provide an additional contribution (Santamouris, 2007).

Although cross ventilation is a useful cooling technique, different climates require different applications. In tropical and humid areas, where wind lowers moisture levels and improves cooling, it is especially advantageous. Cross ventilation, however, needs to be carefully controlled in hot, dry regions to avoid too much heat intrusion. To minimize undesired heat absorption and maintain indoor comfort, controlled ventilation techniques such as ventilation shafts and wind catchers may be more efficient (Givoni, 1998). Strategic application of passive cooling strategies, including wind catchers, can help reduce heat accumulation while maintaining air circulation without undue heat acquisition, especially in Pakistan's arid climate.

Energy efficiency is further enhanced with high-performance windows. By reducing heat transfer, double-glazed or Low-E coated windows with gas-filled insulating layers enhance the building envelope's overall thermal performance (Foster & Oreszczyn, 2001).

Drawings from the simulation models used in this work are included to further elucidate the connection between building form and energy performance. In Pakistan's hot and arid climate, these illustrations show several building forms and their relative energy efficiency capabilities. A thorough grasp of how massing, orientation, and materials affect energy efficiency will be obtained by evaluating options.

Existing Design Features

- **No Open corridors (No Proper natural light & ventilation)**
- **No Proper Orientation followed.**
- **(minimum natural light & ventilation)**
- **The energy efficiency parameter was not followed.**
- **Simple plaster is used on the external finish.**

Specific to climate-wise

- **The same design was used for all types of climate.**
- **No proper landscapes**
- **External finish – Used Dark Materials and color)**

Proposed Design Features

Features (Common for All Climates)

- Open corridors (natural light & ventilation)
- Non-living areas in East and West (protection of living spaces from direct Sun rays/ cold)
- Less deep rooms (maximum natural light & ventilation)
- Energy efficient (low heat/ cold influx) and lightweight infill walls and roof insulation
- Decorative plaster as an external finish (long service life, durability)
- Washrooms provided on both sides (easy access, avoid rush)

Specific to Normal Climate

- Front Courtyard
- Building wings shade each other
- Landscaping provides evaporative cooling
- Trees provide protection from low Sun rays from East & West
- 7' wide verandah with fascia hang (protection from high South Sun rays)
- External finish - light to medium color (reflects heat)

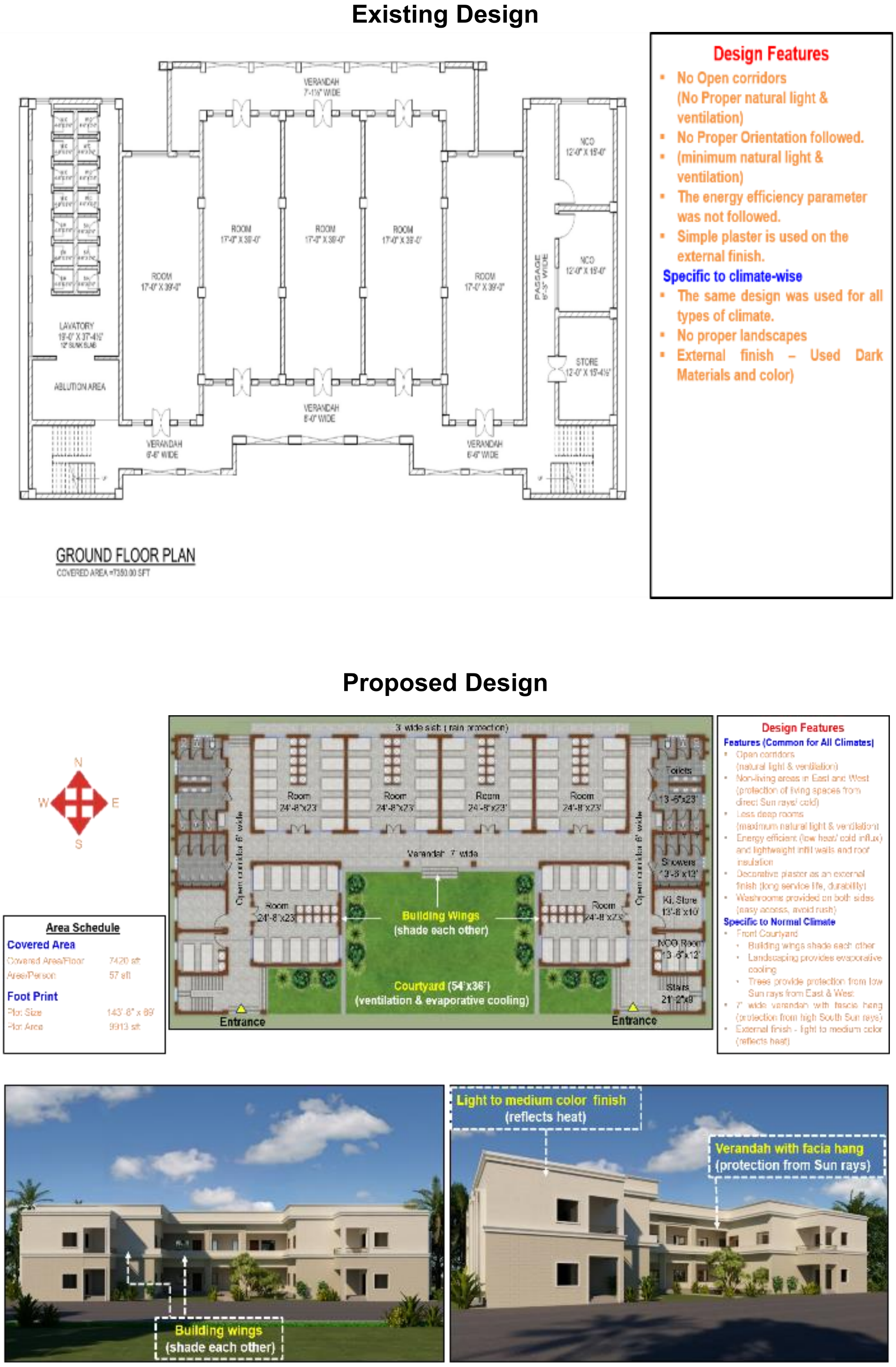
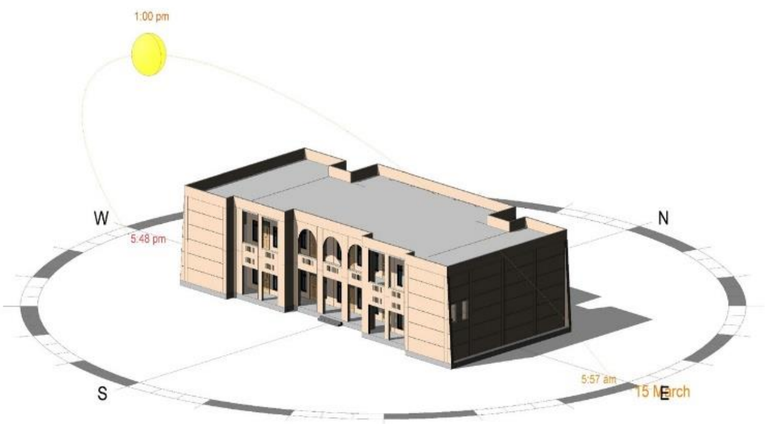


Figure 2: Comparison of Different Energy-efficient designs
Source: Author

Energy-efficient barracks for military soldiers in hot and arid areas of Pakistan can be created by combining these design parameters: thermal mass, ideal orientation, shade, controlled ventilation, and high-performance materials. In the end, these design techniques contribute to a more resilient and sustainable military infrastructure by lowering carbon emissions, increasing indoor comfort, and consuming less energy.

Existing Model



Proposed Model

Figure 3. A 3D model of an energy-efficient barrack
Source: Author

A 3D model of energy-efficient barracks for a hot, dry region can be found here. It exemplifies important design components such as wind catchers, shading devices, a green roof, compact mass, solid walls, and few windows.

Conclusion

In conclusion, an energy-efficient barracks design is essential for reducing energy consumption and lowering carbon emissions in the military. Using different design parameters and architectural techniques such as insulation, shading, ventilation, green roofs, and high-performance windows, energy-efficient barracks can provide a comfortable living environment for military personnel in hot areas.

The orientation of the building plays a crucial role in optimizing natural heating and cooling, while the use of shading devices helps to reduce solar gain and improve indoor comfort. Adequate ventilation, mainly through natural ventilation, can improve indoor air quality and reduce the cooling load of the building.

The use of green roofs can provide insulation, reduce stormwater runoff, and improve air quality. High-performance windows also play an essential role in reducing heat transfer and improving energy efficiency.

By incorporating these design parameters and architectural techniques, energy-efficient barracks can be created that not only improve the living conditions of military personnel but also reduce the military's carbon footprint and energy consumption. This research paper highlights the importance of energy-efficient barracks design and its potential benefits for military personnel and the environment.

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