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# The Role of Earth Tube Heat Exchanger in Improving People's Comfort in Kutch Bhunga Houses to Cool in Summer and Warmer in Winter: An Eco-Friendly Way to Improve Energy Efficiency

Eswara Rao Petta[1], Viswanadha Kumar G.[2,*]

***Abstract***

*To promote sustainable development in the construction sector, it is essential to enhance energy efficiency and abate energy use for building cooling and warming. In a rapidly evolving world filled with innovative solutions and technologies, passive strategies derived from traditional architecture are increasingly used to improve the quality of life while mitigating negative impacts on the environment and human health. Traditional architecture is influenced by local construction materials and techniques, molded by the traditions, culture, and climate of its environment. Traditional architecture, often known as "Architecture without Architects," this approach was first seen in native shelter design and the context of historical structures. The basic principle of traditional shelters is to harness free energy from the natural environment and to make it zero energy consumption. Eventually, traditional architecture's enduring wisdom has shown that it provides a basic level of comfort without relying on active technology interventions. Passive architecture strategies are defined by abating energy use, using architecture and the natural environment to create cooling, heating, light, and ventilation. The natural environment elements are energy sources that include the sun, earth, air, breeze, and water. While adding passive cooling strategies can enhance a shelter's living conditions and improve health quality. This research work will provide the information needed to understand the use of "Earth Tube Heat Exchanger" in new traditional Kutch Bhungas to cool in summer and warmer in winter: An eco-friendly way to improve energy efficiency. The authors state that the use of earth tube heat exchanger strategy at the first stage of architecture design helps to more easily achieve the energy efficiency required nowadays and represents the fundamental base for passive houses and nearly zero-energy buildings. In this way, the authors want to reduce reliance on active cooling and heating systems and to create green architecture without disturbing the environment.*

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**Keywords:** Architectural identity, kutch ethiopian tukul houses, passive cooling and heating application, free energy, green architecture

## INTRODUCTION

In recent years, energy utilization in the architectural sector has increased excessively by 30%–40% for all primary energy. This is because there is increasing pressure on global environmental issues, leading architects and builders to consider traditional architecture knowledge, which is considered energy-efficient and profound. With an increased focus on energy-efficient architectural practices, the intellectual use of the sun, earth, air, breeze, and water becomes a necessity. The sustainable development thought appeared for the first time in the World Conservation Strategy in 1981 and then in the Brundtland Report 1987, in which it was defined as "a new conception of development that meets the present generation without compromising the needs of the next generation." It became the core of the ONU, which cares for Earth [1].

Well-designed, efficient buildings are characterized by an ideal environment for human habitation, while at the same time reducing the use of energy for protective heating, cooling, lighting, and ventilation. Advances in energy efficiency were defined in 2004 by UK energy consultant Janssen as all measures to minimize energy consumption without affecting the level of provided facilities. Architect Ed Mazria in the "Architecture 2030 Challenge" urges carbon-neutral design, which increases the standard for significant changes in energy performance and design thinking [2]. The impact of the habitation construction field generated the development of a series of regulations and recommendations regarding energy-efficient buildings around the world. The instructions regarding nearly Zero-Energy Buildings (nZEB) planned to be implemented in 2020, which are mandatory regulations in the EU countries, highlight the limitation of energy consumption and the use of renewable sources. Therefore, this paper aims to provide a multidisciplinary comprehension of the sustainable benefits through the application of a passive downdraught evaporative cooling strategy in native Kutch Bhungas to enhance energy efficiency [3].

## Statement of Problem

Bhunga is a traditional round house with a conical thatched roof made of local materials like grass, wood, bamboo, stone, straw, and mud, which is commonly found in the Kutch region, Gujarat. It is the most iconic form of traditional architecture, deeply rooted in the region's cultural history, environment, and way of life. The circular plan is believed to symbolize continuity, equality, and unity, which are important values in Kutch cultures [4]. The desert climate of Kutch strongly shaped the Bhunga in its perfect shape, material selection, and use of traditional craftsmen for its construction. In the desert area, Bhungas are built with local, eco-friendly, and climate-responsive materials: stone for foundation, straw-mixed mud for main walls, bamboo for roof frame, grass for roof thatch, wood for openings (doors, windows), lime-added mud for wall plastering, and cow dung slurry for wall and floor finishing. The combination of these materials keeps the house cool in hot seasons and warm in cold seasons. The conical thatched roof provides excellent heat insulation. The old traditional Bhungas of Kutch are the outcome of the prevailing topography, extremes of the climate, and other natural forces [5].

A newly constructed pucca Bhunga house emerged in Kutch district in Gujarat after the 2001 earthquake, initially as relief and temporary shelters, which then became permanent shelters. The new Bhunga consumes more energy to cool in summer and warm in winter annually due to the use of contemporary construction materials and methods, climate change, and the use of low-quality materials. Annually, for more than nine months, the house undergoes heat gain due to the simple hexagon tile roof without provision for ceiling tiles. Several other factors have contributed, such as geographical location, hot and arid climate zone, lack of stringent traditional green building practices and codes, and disappearing traditional artisans and craftsmen [6]. Therefore, there is a need to apply one of the easy passive cooling strategies, i.e., an earth tube heat exchanger, to create better indoor thermal comfort and enhance energy efficiency.

## Paper Aim

The aim of this research paper is to apply one of the simple passive cooling strategies, an earth tube heat exchanger, to improve indoor thermal performance and reduce or eliminate the energy consumption of new Bhungas, especially in semi-arid climates characterized by high temperatures and very low, erratic rainfall in the Kutch region, Gujarat. For this purpose, the authors recommend the use of "Earth Tube Heat Exchanger" for a dual cooling and heating strategy for pucca Bhungas constructed after the Gujarat earthquake, 2001, to improve energy efficiency and to make "Zero-Energy Homes" [7].

### Research Methodology

This study adopts "non-simulation study" as the main investigatory method. This approach often involves collecting and analyzing real-world data through literature reviews, personal observations, qualitative and quantitative surveys, surveys from elders, and individual Bhunga householders. First, the research will briefly explain what traditional architecture is and its advantages and disadvantages compared to contemporary architecture. Second, the research will gather detailed information through a systematic review of books, research articles, and journals about both old and new Kutch Bhungas. Third, conducting a field survey and documentation of both Bhungas in the semi-arid climate. The study involved fieldwork and documentation, data cataloguing, and digitization.

The fieldwork involves field observation, questionnaire surveys with householders, elders, traditional craftsmen, and builders; videos, and photographs; preparing measured drawings; and identification of different construction materials used in new Bhungas. Then the recorded field data were converted into vector-based 2D and 3D drawings. Fourth, comparative analysis and conclusions should be drawn regarding indoor thermal comfort and energy consumption. Fifth, a brief review of the passive cooling strategy of earth tube heat exchanger and its applications in new Bhungas to enhance thermal comfort naturally and to minimize or eliminate the use of energy. Sixth, the authors will design an updated new Bhunga unit with all architectural details, a summary of findings, and contributions [9].

### Summary of Findings and Contributions

Generally, in traditional homes, passive thermal comfort is mostly achieved by using eco-friendly building design, the use of native materials, and native construction methods. Such traditional structures remain cool in summer and warm in winter without relying on energy-intensive systems. The same principle is used in old Kutch traditional Bhungas for Gujarat's climate regions. They are made of 100% local and natural materials; they possess high thermal efficiency, a round structure for wind resistance, low-carbon footprint construction, climate-responsive architecture, recyclable and biodegradable, and in harmony with their surroundings [10].

But newly constructed Bhungas after the Gujarat earthquake, 2001, lost the sustainable principles and passive design strategies due to various reasons, primarily the need for quick construction. They were built with contemporary hybrid materials and construction techniques, but the shape remains circular. Foundations are made of stone, walls are made of HCBs, ring beams are made of RCC, and cement mortar is used for finishing. The conical roof is made of timber with Mangalore tiles without a ceiling. Such pucca Bhungas maintain the cultural identity of Kutch architecture but adapt it to modern needs, making them a blend of traditional design and improved structural stability, but they lack indoor thermal comfort. These Bhungas undergo heat gain for more than nine months annually; this causes the use of active cooling systems with high energy consumption [11].

The indoor thermal comfort and energy reduction can be achieved by harnessing different passive cooling strategies. Given the geographical location, desert terrain, and climate, the authors propose the most cost-efficient passive cooling and heating strategy of an earth tube heat exchanger to cool Bhungas in summer and warm them in winter to enhance energy efficiency. This research paper reveals several significant findings, such as a practically proven vernacular zero-energy system of passive ventilation, to reduce or eliminate total annual energy consumption. The findings of this research will provide guidance to architects and planners on energy-saving potentials of applying traditionally proven passive cooling and heating strategy in desert climate zones in Gujarat and places with similar climatic contexts. Furthermore, it is hoped that this paper will stimulate academic interest into this under-researched area of investigation [12].

## THEORETICAL FRAMEWORK AND RESEARCH DESIGN

### Traditional Architecture

Traditional architecture developed over time, illustrating how people lived and worked in their areas. It was designed to fit the climate, terrain, and history of the place. It also demonstrates the ingenious ideas that past generations employed to live in harmony with nature. This knowledge should be passed on to future generations as a way of demonstrating respect for nature, the environment, and traditional ways of life. Today, with rapid technological advancements and prolific new construction, designers often disregard the local climate when building. Traditional architecture, too, is almost forgotten. However, much can still be learned from these older buildings, which are better suited to the local climate and culture.

In the past, the connection between traditional buildings and local climate has been widely studied, while culture has often been overlooked [13]. Construction techniques in countries with similar climates can differ greatly, and some methods are even applied in very different climatic regions. In his book, *House Form and Culture*, Amos Rapoport discusses how traditional architecture aims to achieve a balance between nature and human habitation by means of livelihood, culture, and security.

Traditional architectural history indicates that utilizing passive cooling methods helps create comfortable interior living and working environments, depending on the local climate. For example, in hot areas, techniques such as moving air, evaporative cooling, and building massive structures that store heat are employed. In colder regions, insulating materials are used to block cold winds and passive solar heating is employed. In traditional buildings, it is important to consider how the design adapts to the climate. Bernard Rudofsky provides excellent examples in his book, *Architecture Without Architecture*. He talks about things like the wind scoops in Bad-gir, Pakistan; planted wind barriers in Japan; shelters in Italy that protect against snow and cold; semi-covered streets in Africa; Japanese homes with sliding doors; and wind towers and brise-soleil in the Middle East.

## Kutch Climate and Geographical Location

The arid northwestern region of Gujarat encompasses the Kutch district. The region of Kutch consists of the Ranns, which are salt-encrusted wastelands rising only a few meters above sea level. Monsoon floods are divided into the Great Rann to the north and the Small Rann of Kutch to the east. Kutch is a large district in the state of Gujarat. It is renowned for its desert landscape, rich cultural heritage, and vibrant festivals. It is notably home to the Rann of Kutch, the white salt desert, attracting tourists worldwide. It is the largest district in Gujarat state, covering an area of 45,612 sq km.

Kutch has a hot–arid desert climate, characterized by extreme temperatures, minimal rainfall, and high evaporation. Summers are extremely hot, often exceeding 45°C, while winters are cool and dry [13]. Rainfall is sparse and inconsistent, typically occurring during the brief monsoon season. The region is also subjected to strong desert winds, frequent dust storms, and significant temperature fluctuations between day and night. Due to its coastal location, Kutch also experiences occasional cyclones and high humidity. The classification of climate regions of Gujarat is shown in Figure 1.

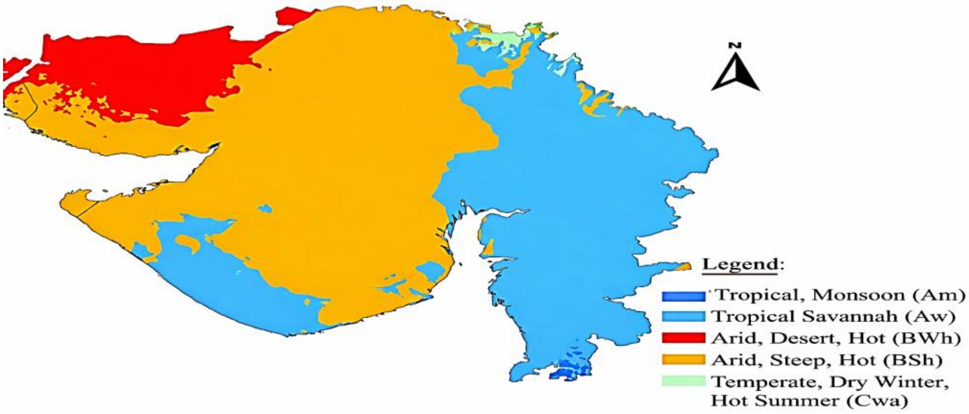

**Figure 1.** Map showing climate regions of Gujrat, India.
*(Source: Koppen Map v2 IND Gujarat 1991-2020).*

The climate zones of Kutch, Gujarat, boast a vibrant cultural site with traditional circular houses, known as Bhungas, which include “Traditional Bhunga” and “Pucca Bhunga”. The old traditional Bhungas were constructed long ago, but their official recognition dates to June 16, 1819, due to the earliest recorded earthquake in Kutch. The old Bhunga was built with locally sourced materials such as mud, clay, sand, bamboo, thatch, timber, and stones, requiring low transportation energy and almost zero industrial processing. The eco-friendly features of the Bhunga include the use of local materials, high thermal efficiency, a circular shape for wind resistance, low-carbon footprint construction, climate-responsive architecture, recyclability and biodegradability, and harmony with its surroundings [14].

The Pucca Bhunga is a newer design, constructed after the Gujarat earthquake in 2001. It was built with contemporary materials and construction techniques, but its shape remains circular. The foundation is made of stones, the walls are made of HCB, ring beams are made of RCC, and cement mortar is used for finishing. The conical roof is made of timber with Mangalore tiles, without a ceiling. Kutch architectural Pucca Bhungas maintain the cultural identity with the same form, but they are missing the eco-friendly features found in the old Bhunga. This Bhunga experiences heat gain for more than nine months annually, which necessitates the use of active cooling systems and energy consumption. The reason behind the high energy consumption of Pucca Bhunga in Kutch, Gujarat (which is very hot in summer and very cool in winter), is the need for cooling and heating annually to create thermal comfort. Therefore, there is an urgent need to implement passive cooling and warming strategies to enhance indoor thermal comfort and to minimize or eliminate energy consumption [15].

## Background of the Study Area

Gujarat is located in the western part of the country and has the longest coastline. The study area, located in the Great Rann of Kutch near the Little Rann of Kutch, lies between 23°40'N–23°51'N latitude and 71°03'E–71°19'E longitude, and this region passes through the Tropic of Cancer. It covers an area of 45,612 square kilometers. Historical records show that the ancient Kutch region of Gujarat was home to Paleolithic communities. It was a significant area for various ancient cultures, including the Mesolithic, Chalcolithic, and Harappan people, from the early to the late Harappan periods. Kutch was a key center of the Indus Valley Civilization and was ruled by the Jadeja dynasty of the Rajputs until India's independence in 1947, with Bhuj as its capital (Figure 2).

**Figure 2.** Map showing the kutch district of Gujrat, India.
*(Source: Reserch article of First of the Miocene hominoid Sivapithecus from Kutuch, Gujarat state, western India)*

Kutch is in an area that experiences frequent earthquakes and has suffered from major, damaging quakes such as the one in 1819 and the devastating 2001 Bhuj earthquake. The land in Kutch has a mix of salty, dry soil and is primarily composed of clay and sand deposited by the Rann. After the monsoon rains, much of the land becomes covered with a layer of salt. Although farming is challenging in this area, the highlands offer excellent natural grazing areas [16].

### Ethnic Communities in Kutch

Kachchh is a cultural area in Gujarat well known for its rich culture. The district is home to many different groups and communities. Both nomadic and semi-nomadic peoples, as well as artisans, can be found living there. The Gujarati Ahirs are one of the larger groups in Kachchh. Many of them came to this area after migrating from nearby regions like Marwar in western Rajasthan, Sindh, and Afghanistan, over many centuries. Most of the people in Kachchh are Hindu or Jain [17].

Kutch costumes are distinctive, expressed through clothing adorned with embroidery and mirror work. Mirror work and embroidery are integral parts of Kutch handicrafts, irrespective of the community group. Community identity was expressed by women through embroidered dress codes. For example, Garacia Jat women usually wear only red or black chunis. Rabari women wear black open blouses or cholis along with odhnis that cover their heads. In rural areas, women often wear Chaniya cholis all year round. A typical Kutch costume is not complete without Abha or Kanjari. Abha is a special type of choli that women wear. "Kanjari" is a long blouse featuring beautiful embroidery and mirror work. Most men in Kutch wear loose trousers, a long-sleeved under-jacket, a short coat, and a plain or silk-bordered cloth. Usually, men prefer to wear white clothes, but Muslims often wear colored clothes instead [18].

### Traditional Architecture in Kutch

The development of traditional architecture began when people started constructing their homes from locally available materials, adapted to their needs. Even before the advent of architects, humans were able to build climate-responsive structures as a simple response to societal necessities. Kutch, in Gujarat state, places great value on traditional architectural identity and is one of the areas that has made a significant contribution to world traditional architecture. The traditional houses in Kutch are locally known as "Bhungas," built by different ethnic peasant societies, and are constructed from local organic materials to suit the geography, terrain, local climatic conditions, people's culture, and customs. There are two types of Bhungas: "Old Bhungas" and "New Bhungas" (also known as Pucca Houses), differentiated by their construction materials and methods, both of which are described below [19].

#### *Old Bhunga of Kutch*

It is a single-roomed circular house built by Kutch Palaeolithic Age communities. Its official identification is linked to the devastating earthquake in 1819. The old Bhungas are innovative huts featuring round walls and conical thatched roofs. The most influential factors in the development of Bhunga design are climate, locally available materials, calamities, and culture. Traditionally, a single family constructed three Bhungas: one for men, a second for women and children, and another for storage. The diameter of the Bhunga varies from 3m–6m, with the maximum size typically for men, average size for women and children, and minimum size for storage, as shown in Figure 3. Bhungas are primarily made of organic, renewable materials such as mud, wood, stone, bamboo, cow dung, dry grass, and cane leaves. The round walls are constructed with mud bricks, in-situ mud (COB), or wattle and daub. The wall surface is finished with clay and cow dung slurry. The floor is made of mud and its surface is finished with cow dung slurry. The conical roof is made of native wood with bamboo purlins and thatched with special grass, wheat, or maize straws. The houses are decorated with various ornaments to reflect the life and culture of the Kutch people.

The round Bhungas are more than mere dwellings; they demonstrate the ingenious knowledge of the local people. They are built to withstand the challenging weather and potential earthquakes in the area, and they also reflect the vibrant culture of their inhabitants.

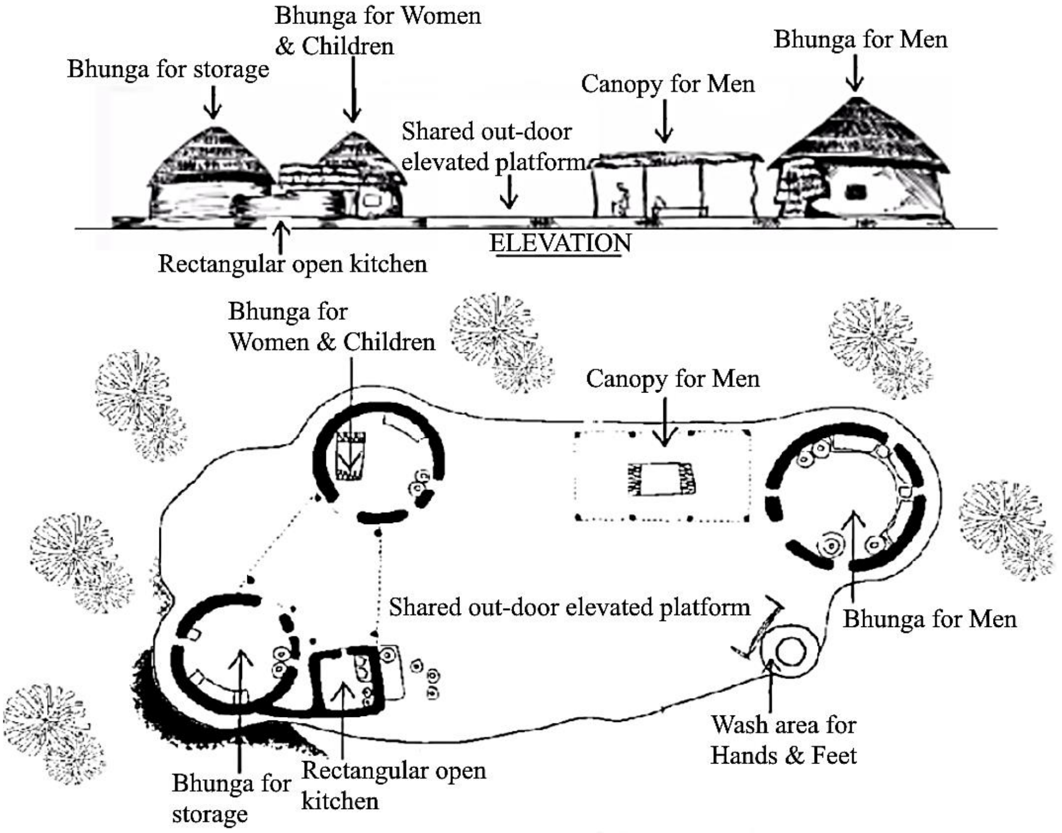

**Figure 3.** Bhunga settlement pattern for single family at Kutch.
*(Source: Drawing prepared based on field study)*

### *Pucca Bhunga of Kutch*

Pucca or New Bhungas appeared in Kutch, Gujarat (specifically in Bhuj), after the earthquake on January 26, 2001, as part of relief and temporary shelter efforts. Its basic form is similar to the old Bhunga, featuring a circular wall with a conical roof. The circular foundation and plinth are made of stones or solid cement blocks with cement mortar. Ring RCC beams are provided at the plinth and lintel levels. The walls of the superstructure are made of rammed earth with vertically placed steel rods at different intervals to strengthen them. The circular rammed wall is constructed with steel shuttering. Some of the walls are constructed with manually pressed stabilized compressed earthen blocks.

The wall height is approximately 2.5m–2.8m. The circular conical roof becomes a hexagonal roof made of a timber frame with Mangalore tiles. The provision of wooden beams on the circular walls with a king post truss is similar to that of old Bhungas. Except for the rammed earth walls, all materials used are contemporary and are not environmentally friendly. The house has one door opening and two windows. The door is made of timber; the window frame is made of timber with a metal grill, and the timber frame has glass panels. The architectural and construction details of the Pucca Bhunga are shown in Figures 4 and 5.

The Pucca Bhunga architectural shape represents the old Bhunga and the cultural identity of the community. It improved structural stability with a longer life span, similar to the contemporary built environment. However, it lost the sustainable principle and neglects the passive design strategies found in old Bhungas. Annually, it experiences heat gain for more than nine months due to the climate, primarily from Mangalore tile roofs without any ceiling. This heat gain was proven by the calculation of heat conduction, $Q_c = A \times U \times \Delta T$. During our investigation, most households are currently using active cooling methods such as mechanical ventilation, coolers, and air conditioners, as shown in Figure 6. These active cooling systems consume more energy.

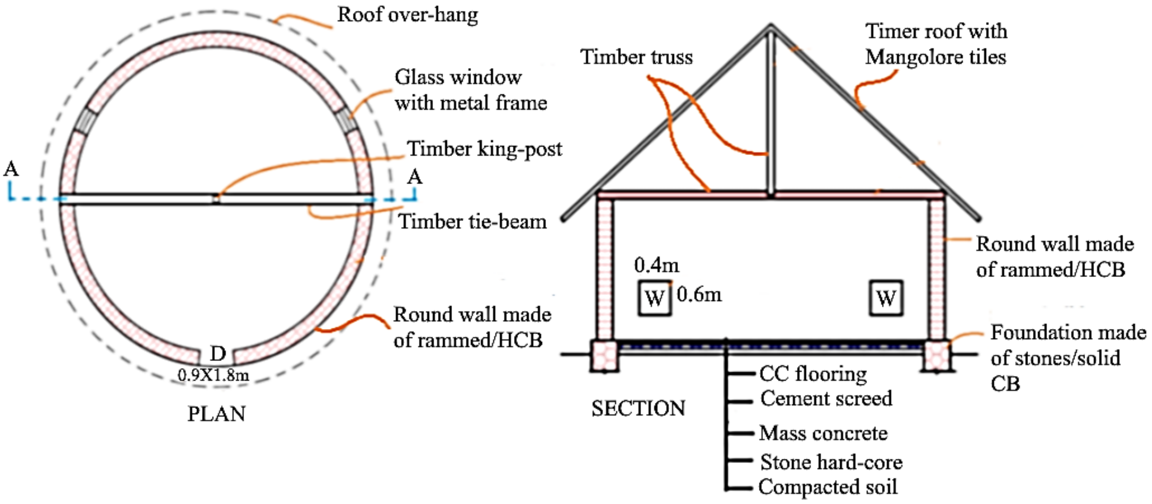

**Figure 4.** Architectural details of Pucca Bhunga in Kutch, Gujrat.
*(Source: Drawing prepared based on field study)*

A. Steel shutter for Rammed earth wall B. Filling the sthutter with rammed earth C. Brick wall on stone-masonry plinth

D. Hexagonal conical timber-roof E. Hexagonal Mangolor tiles-roof finishing F. Mangolor tiles-roof interior details

**Figure 5.** Construction details of Pucca Bhunga after Bhuj earthquake, 2001.
*(Source: Kutch earthquake reconstruction by Hunnarshala foundation)*

A. Using Ceiling Fan in Pacca Bhunga to Cool B. Using Air-Conditioning in Pacca Bhunga to Cool

**Figure 6.** Using active cooling systems in Pacca Bhungas.
*(Source: Nani Dadhra housing in Bhuj afte earthquake, 2001)*

The indoor comfort and energy savings in Pucca Bhunga are achieved through the use of various passive cooling methods. Considering the location, which is a desert area with specific climate conditions, the author suggests the most cost-effective passive cooling and heating method, known as an "earth tube heat exchanger." This system helps to cool Bhungas during summer and heat them in winter. The research paper presents several important results, including the successful implementation of a traditional, zero-energy system using passive ventilation, which can significantly reduce or eliminate total annual energy use. The findings from this research will help architects and planners understand the potential for energy savings by using well-established passive cooling and heating techniques in desert regions like Kutch in Gujarat and other areas with similar climates. It is also hoped that this paper will encourage academic interest in this area, which has not been widely studied previously [5].

## Comparative Study on Old and New Bhungas

To achieve the research aim, it is important to compare the old and Pucca Bhungas in order to examine indoor comfort and energy usage. Based on the findings from this comparison, the author will develop the theoretical framework and research design (Table 1).

**Table 1.** Comparative analysis between old bhunga and pucca bhunga.

| **Descriotion** | **Bhunga types in Kutch, Gujrat** | |
|---|---|---|
| | *Oled Bhunga* | *New/Pucca Bhunga* |
| Siting | Flat terrain | Flat terrain |
| Bhunga shape | Circular with conical roof | Circular with conical roof |
| Fundation | COB/rubble stones with mud-mortar | Stone/solid CB with cement mortar |
| Plinth | Rised platform made of stones with mud/lime mortar | Stone/solid CB with cement mortar |
| Pilnth beam | No | RCC ring-beam |
| Wall | Made of COB/wattle and daub | Made of rammed earth with vertical steel/Red-brick/HCB with cement mortar |
| Lintel/roof-beam | No | RCC ring-beam |
| Roof | Conical roof made of bamboo/local wooden frame with grass thatching | Conical hexagonal roof made of timber and thatching with Mangolor tiles |
| Flooring | Made of COB/rubble stone with mud-mortar finished with mixture of clay with cow-dung slurry | Contemporary cement flooring |
| Materials type | Eco-friendly | Except rammed earth, all are non eco-friend |
| Ventilation system | Passive ventilation | Active ventilation |
| Relation with nature | Mixed with nature | Un-miexed with nature |
| Thermal comfort | Cool in summer, warm in winter | Very hot in summer (50°C above) and very cool in winter (below -8°C) |
| Adoptation | 100% Kutch deser community accepted | Not adopted by the Kutch desert community |

As per the above analysis, the author concludes that the Pucca Bhunga, which was constructed after the Bhuj earthquake in 2001, is using active strategies to create thermal comfort during the hot and winter seasons due to multiple reasons. At present, the Kutch district is occupied by many Pucca Bhungas, which consume much energy. Therefore, it is important to use passive cooling techniques to make homes thermally comfortable, save energy, and create Zero-Energy Homes.

## Strategy of Passive Cooling and Warming

Passive cooling and warming utilize free, renewable energy from natural sources (above or below the earth's surface) to keep buildings cool in summer and warm in winter. This approach helps reduce the use of active systems. Using this method lowers the temperature difference between inside and outside, which improves indoor comfort and enhances living and working conditions in buildings. It also helps lower environmental impacts such as energy use and greenhouse gas emissions. In recent years, there has been growing awareness regarding the use of passive design for heating and cooling in buildings, as part of a shift toward green architecture. Passive architectural strategies are systems that use less energy and avoid new active technologies; these strategies are a key part of achieving near Zero-Energy Buildings. The main reason for using passive strategies is to improve energy efficiency.

In traditional architecture, passive strategies are used to obtain free energy for cooling, heating, and ventilation by working with elements of nature such as earth, air, and wind. There are many types of passive cooling methods, including building orientation, natural ventilation, shading, thermal insulation, courtyard design, evaporative cooling, wind towers, earth tube heat exchangers, downdraught cooling, thermal mass, green roofs, and so forth. These strategies are especially useful in desert climates like Kutch in Gujarat for cooling in summer and warming in winter. The author intends to apply a very simple and affordable passive strategy called the "Earth Tube Heat Exchanger" to improve indoor comfort in Kutch Pucca Bhungas. This approach aims to increase energy efficiency and reduce or eliminate the need for energy consumption.

## Physical Form and Concept of Earth Tube Heat Exchanger

An earth tube heat exchanger is a natural, energy-saving system that helps cool or warm the air used to ventilate a building. It works by utilizing the steady temperature found underground. At a depth of about 2–3 m, the ground temperature remains almost constant throughout the year. This stable temperature is called the "undisturbed earth temperature" (EUT). In summer, it is cooler than the outside air and warmer in winter. When air from outside is passed through pipes buried underground, it is cooled in summer and warmed in winter before being brought into the building. This system can be used for both cooling during hot weather and heating during cold weather.

The concept of using an earth tube heat exchanger is not new; it has existed since ancient times. This method of cooling without using energy has been employed for a long time by people such as the ancient Greeks, Persians, and other civilizations before Christianity, and it is still used today. For example, during the Middle Ages, Italians used caves and underground tunnels to cool or warm the air before it entered their homes. Today, the system uses a set of pipes buried underground to move air either passively or with the help of a fan. In summer, the air brought into the building is cooler because the ground is usually cooler than the outside air.

Conversely, during winter, when the outside air is colder than the ground temperature, the process works in reverse, and the air is warmed before entering the building. The method of moving heat into and out of a building using an earth tube heat exchanger has been carefully examined through both theoretical and experimental approaches. By reviewing past research from various scientists, a clearer understanding of how this system operates can be gained. According to the study by Sehili et al. [1], using an earth-air heat exchanger can lower the energy needed for buildings.

The research team led by Shukla et al. [2] developed a thermal model to heat a greenhouse by using various combinations of an inner thermal curtain and an earth air heat exchanger. Another team, led by Bansal et al. [3], investigated how effectively the earth can be used for cooling during summer in Jaipur, India. They examined an earth air heat exchanger that was 23.42 m long and operated in cooling mode. The study tested temperatures ranging from 8 °C to 12.7 °C, with airflow speeds between 2–5 m/s through steel and PVC pipes.

A research team led by Mihalakakol et al. [4] investigated the impact of different ground surface boundary conditions on the efficiency of an earth-to-air heat exchanger system. All the research references stated that the application of an earth tube heat exchanger is a sustainable passive strategy for cooling in summer or warming in winter for the built environment, especially in hot and arid climatic regions. A detailed illustration of an earth tube heat exchanger model is shown in Figure 7.

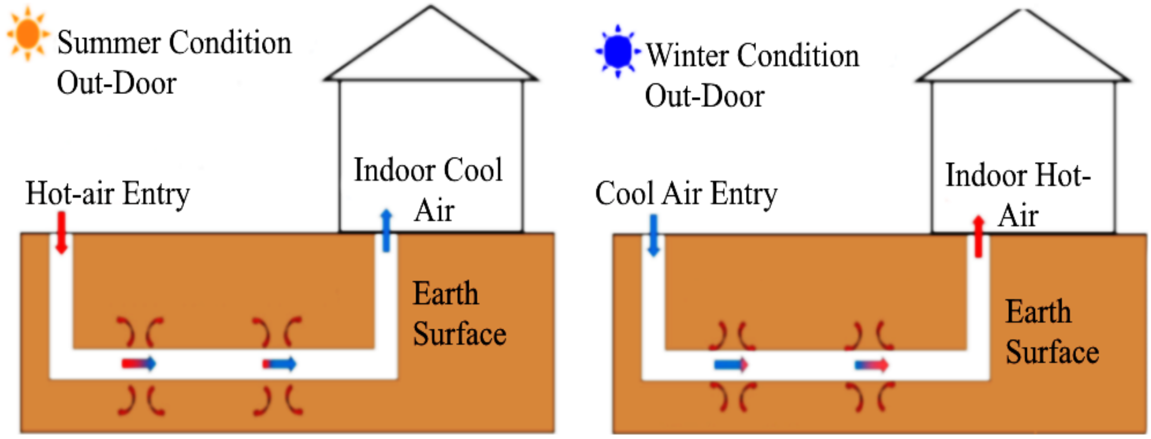

**Figure 7.** Earth Tube Heat Exchenger Working Principle.
*(Source: Chong Zhang; Jinbo Wang; Liao Li, 2020)*

## DISCUSSION

### Application of Earth Tube Heat Exchanger in Kutch Pucca Bhunga

After a detailed study and analysis of Pucca Bhunga-houses in the hot-arid desert climate of the Kutch district of Gujarat, uninhabitable thermal conditions are found inside due to multiple reasons listed briefly above. The difference in thermal comfort needs between old Bhunga and Pucca Bhunga is largely due to the use of hybrid materials and construction methods. At present, all of the Pucca Bhungas achieve indoor thermal comfort through the use of active cooling strategies (fans, coolers, and A.C.), which leads to increased energy consumption, energy demand, and electricity bills in the study area. The aim of this research is to apply a more suitable passive cooling and heating strategy to improve indoor thermal performance and reduce energy consumption in both summer and winter. To achieve this aim, the author designed and developed an earth tube heat exchanger for passive cooling in summer and warming in winter to suit the Bhungas' form, local climate, and community socio-economic conditions.

### Experimental Setup

Many research reports show that just a few meters below the earth's surface, a relatively constant temperature is maintained year-round. While the air temperature above the ground changes with the seasons, soil temperature is much more stable. Archnotes et al. [6] reported that the underground temperature at a depth of 2–3 m is about 10–20°C year-round. Girija Sharan et al. [7] reported that the earth temperature at 2.5 feet is about 20°C, at 5 feet is about 15°C, at 7 feet is about 10°C, and at 10 feet is about 7°C, which remains constant.

Bisoniya et al. [8] reported that the earth's temperature at a depth of 1.5–2 m remains fairly constant throughout the year, approximately 6–20°C. This constant temperature is known as the earth's undisturbed temperature (EUT). The EUT remains higher than the ambient air temperature in winter and lower than the ambient air temperature in summer. The experimental setup also requires baseline information about the study area's topography, climate, and meteorological conditions, as described below.

### *Topography Conditions*

The topography of Kutch is divided into habitable and uninhabitable regions. The habitable topography in Kutch is known as the "Kutch Mainland" and is mostly suitable for human habitation, flora, and fauna. The topography of the mainland is a rugged, rocky upland area that forms the habitable core of the Kutch Peninsula. The semi-arid to arid climate, hilly topography, and poor soil fertility gave rise to tropical thorn scrub vegetation, such as small leaves, thick bark, thorns, and deep roots. The overall cover of this vegetation is sparse. Trees are very rarely found; they are typically low-growing, low-height, and deciduous. Kutch has varied soil types, such as saline soil, alkaline soils, sandy soil, clay, and black cotton soils, due to its arid climate and saline geology.

### *Climate and Meteorological Conditions*

Kutch is hot during the summer months; the minimum temperature is about 22 °C, and the maximum temperature exceeds 45 °C. Summers in Kutch are very scorching, and winters are pleasant. The relative humidity in Kutch varies between 43.5% during March and 77% during August. The monsoon starts in June and continues until September. Winter months range from November to February.

#### *Temperature*

The temperature in Kutch changes slightly during different seasons. The lowest temperature is between 13°C and 15°C, and the highest is above 40°C. Summers are mostly hot, and winters are cool. The hottest time of the year is in April and May, while the coolest is in January and December. The analysis of maximum temperature data from 2021–2025 is shown in Table 2 and Figure 8. This analysis helps to understand how the maximum temperature changes each month over several years. Based on this information, the author will decide the depth and length of the earth tube to be buried so that the high temperature can be converted into a comfortable room temperature.

**Table 2.** Maximum Temperature from 2021–2025 at Kutch.

| Months | Minimum in 2021 | Minimum in 2022 | Minimum in 2023 | Minimum in 2024 | Minimum in 2025 |
|---|---|---|---|---|---|
| Jan | 26 | 26 | 26 | 27 | 27 |
| Feb | 31 | 31 | 34 | 29 | 32 |
| Mar | 36 | 38 | 36 | 33 | 35 |
| Apr | 38 | 41 | 38 | 37 | 40 |
| May | 37 | 40 | 39 | 39 | 38 |
| Jun | 35 | 38 | 35 | 37 | 34 |
| Jul | 33 | 31 | 32 | 33 | 32 |
| Aug | 33 | 31 | 31 | 31 | 32 |
| Sep | 32 | 33 | 33 | 33 | 32 |
| Oct | 34 | 36 | 34 | 35 | 32 |
| Nov | 32 | 33 | 32 | 32 | 30 |
| Dec | 27 | 29 | 28 | 27 | 0 |

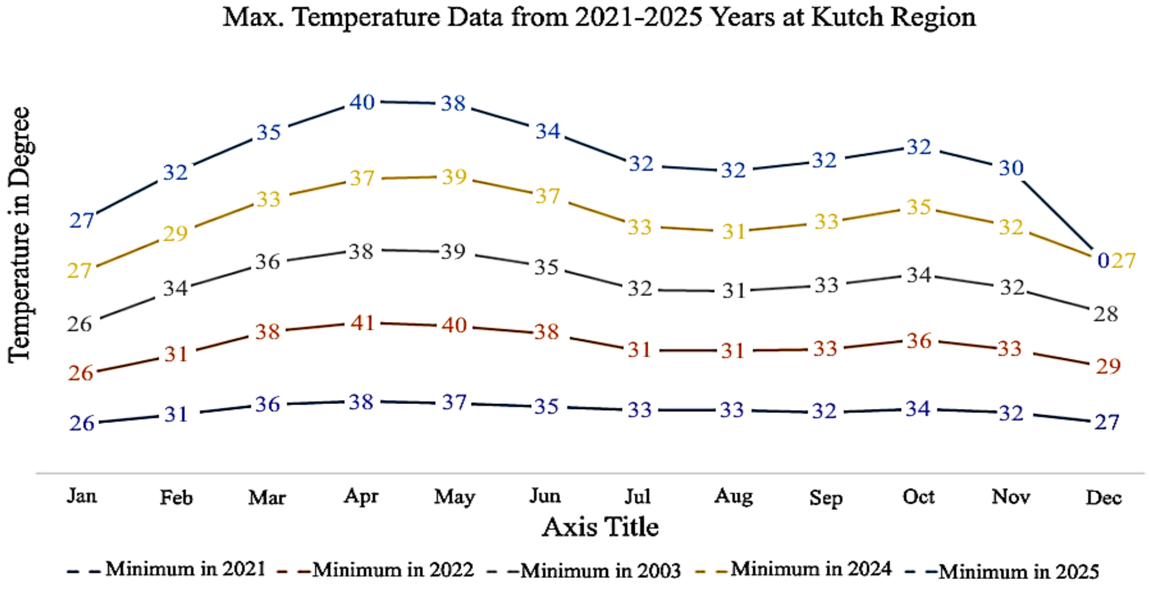

**Figure 8.** Chart diagram showing Max. temperature analysis from 2021-2025 years at kutch region.

*Wind Speed*

Wind speed is the movement of air. Wind in an area consists of two types: permanent and gust (sudden) wind. Wind speed is the rate at which air moves in a direction, and it is measured in kilometers per hour (km/h) or meters per hour (m/h). The wind speed of an area is measured as maximum and minimum wind speed. The wind speed analysis for Kutch from 2021–2025 is illustrated in Table 3 and Figure 9. This analysis helps to understand how the maximum wind speed changes each month over several years. Based on this information, the author will decide whether or not to use an air blower at the air inlet to force air into a suitable earth tube diameter and length to supply cool air to the required indoor room space.

**Table 3.** Maximum Wind Speed from 2021–2025 at Kutch Region.

| Months | Maximum in 2021 | Maximum in 2022 | Maximum in 2023 | Maximum in 2024 | Maximum in 2025 |
|---|---|---|---|---|---|
| Jan | 20.4 | 21.1 | 22.7 | 19.9 | 21.7 |
| Feb | 19.2 | 18.9 | 18.8 | 24.4 | 21.8 |
| Mar | 21.9 | 23.7 | 22.7 | 25 | 25.5 |
| Apr | 26.2 | 30.4 | 27.3 | 28.8 | 32.7 |
| May | 32.9 | 36.6 | 33.4 | 34.5 | 34.1 |
| Jun | 32 | 32.8 | 37.6 | 33.4 | 33.1 |
| Jul | 33.7 | 28.6 | 26.9 | 31.9 | 31.7 |
| Aug | 30.3 | 24.8 | 36.7 | 33.2 | 28.7 |
| Sep | 22.5 | 21.9 | 28.4 | 25.7 | 28.2 |
| Oct | 18.7 | 16.8 | 20.4 | 19.4 | 23.8 |
| Nov | 18.3 | 14.3 | 18.2 | 15.3 | 16.7 |
| Dec | 20.1 | 18.6 | 20.4 | 21.4 | 20.1 |

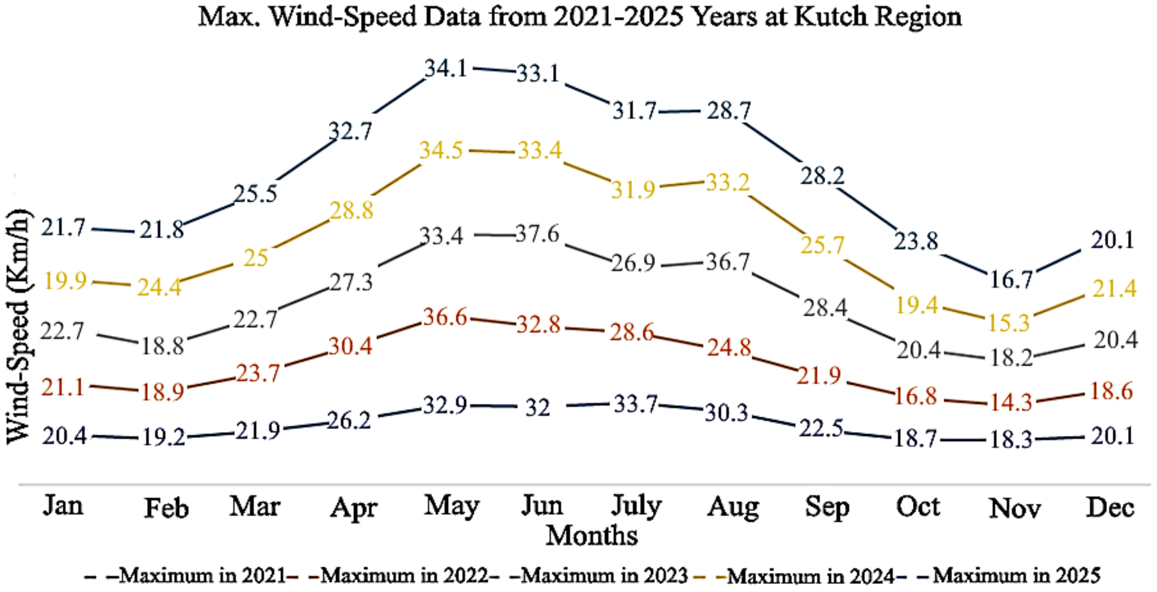

**Figure 9.** Chart diagram showing Max. wind-speed analysis from 2021-2025 at kutch region

*Wind Direction*

Wind direction is the direction of air blowing in a given area. It is measured in geographical directions such as N, E, S, W, NE, EW, SE, and SW. The wind blow direction of the Kutch study area is shown in a wind-rose diagram in Figure 10. The annual wind-blow direction includes N, NNE, NE, NW, W, WNW, WSW, S, and SW. From the above analysis, the author confirmed that strong wind-blow occurs from west to south-west. Therefore, in the experimental setup, the earth tube heat exchanger inlet should be located in the west to south-west direction to intake enough air without using any blowers.

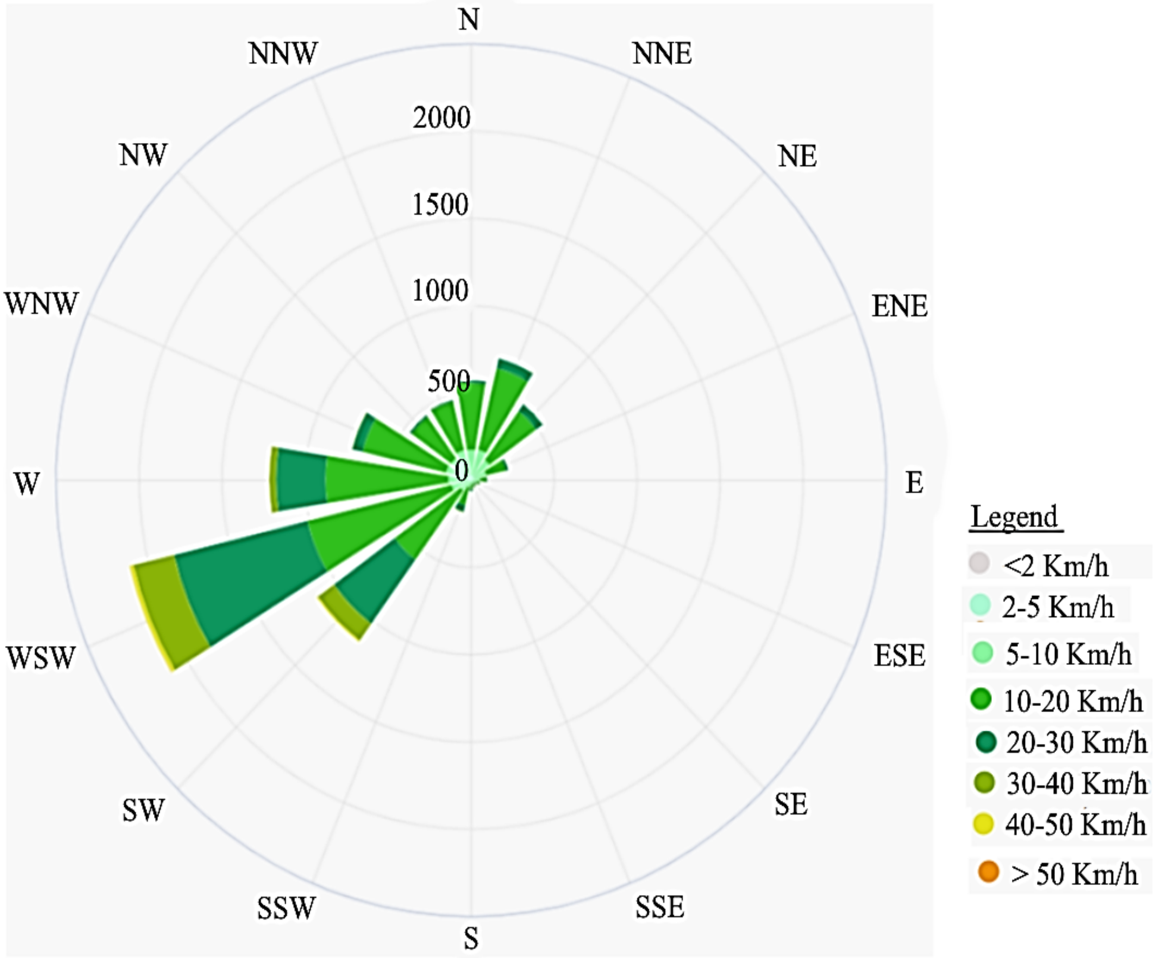

**Figure 10.** Wind-rose diagram of study area of kutch reagion.

***Materials and Methods for Physical Experimental Setup***

The earth tube heat exchange system was set up in a Pacca Bhunga. A minor change was made to the hexagonal conical roof by adding ceiling tiles and using traditional mortar to reduce heat transfer from the outside. All other parts of the structure remained the same with no changes. Based on the summary of temperature, wind speed, and direction, the author suggested placing the earth tube heat exchanger in the WSW area. The materials needed for the experimental setup are locally available compressed soil pipes with a diameter of 12 cm and a length of 1.8 m. The total length of the pipe network should be between 20 m and 35 m, and it can be laid horizontally, in a zig-zag pattern, or vertically depending on the available space, as shown in Figure 11. The inlet of the pipe is covered with a mosquito net to prevent insects and debris from entering.

A temperature sensor is used to measure three different temperatures: outdoor ($T_o$), indoor ($T_i$), and the middle of the pipe inside the ground ($T_m$d). The indoor temperature mainly depends on three things: outdoor temperature ($T_o$), soil temperature ($T_s$), the length of the buried pipe, and its diameter. To find the final indoor temperature ($T_i$), a physical experiment is conducted on the ground. During a hot summer, the outdoor and indoor temperatures are measured over a period of one or two months. Then, the data is analyzed and summarized. For the setup of this experiment, the most important data needed is the soil temperature ($T_s$) at different depths, along with the pipe's length and diameter. The indoor or outlet temperature ($T_o$ut) can be calculated using the "steady convective heat transfer along the pipe equation" (1):

$T_o$ut = $T_s$ + ($T_i$n - $T_s$) exp (–[missing exponent]) and the equation details are given separately.

- $T_{out}$ = Out-let air temperature
- $T_{in}$ = Inlet air temperature
- $T_s$ = Soil temperature
- $U'$ = Overall heat-transfer coefficient per unit length ($W \cdot m^{-1} \cdot K^{-1}$) = $U$ ×pipe perimeter
- $U$= overall heat transfer coefficient per unit area ($W \cdot m^{-2} \cdot K^{-1}$),
- $\dot{m}$= mass flow rate of air (kg/s), $\dot{m} = \rho \dot{V}$,
- $c_p$= specific heat of air (≈1005 J/kg·K).

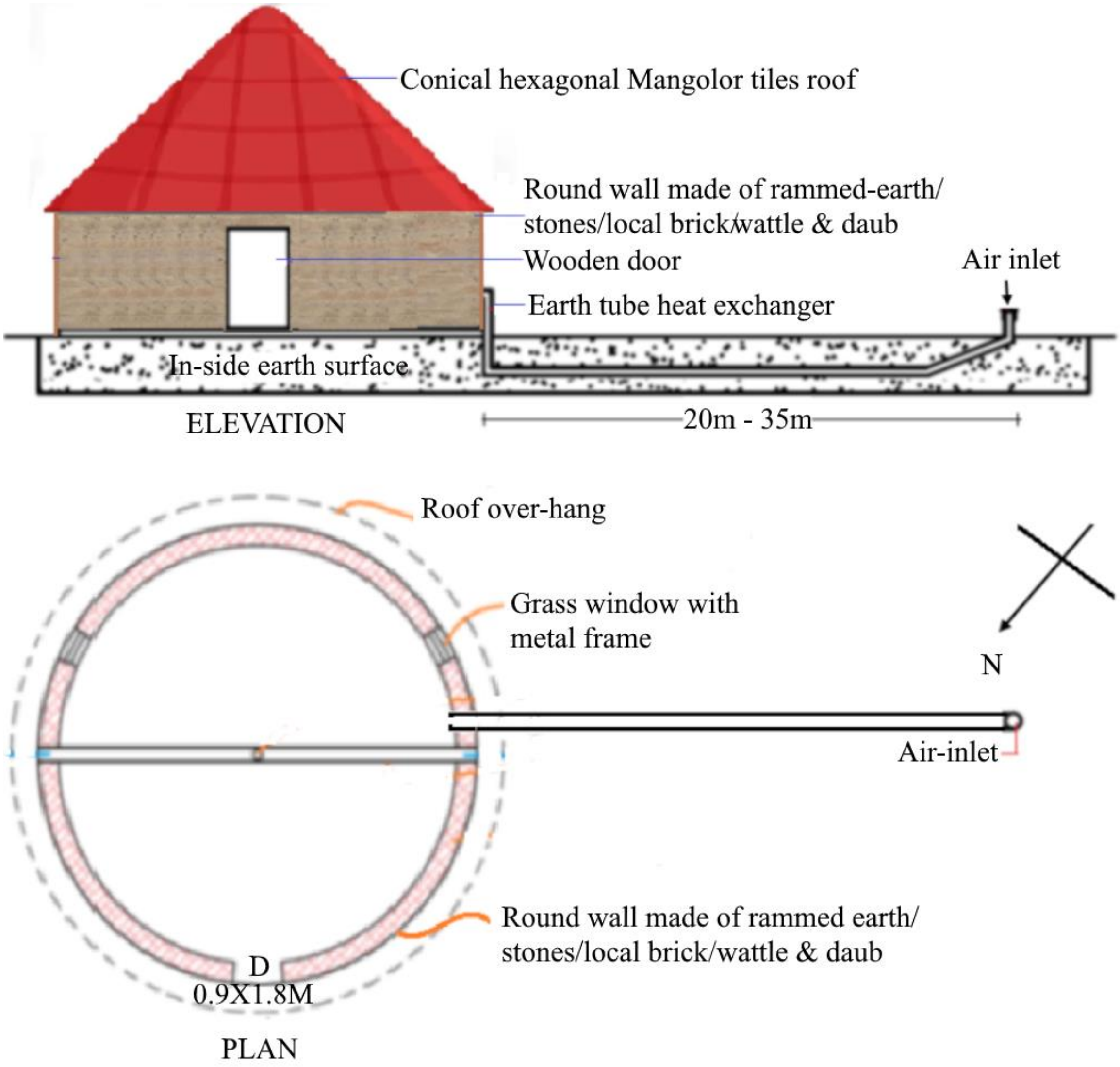

**Figure 11.** Architectural details of earth tube heat exchange Expermental Set-up.
*(Source: It was prepared by the author based on literature review & field study, 2025)*

To find the suitable pipe length and diameter, the author used the above equation to find the outlet temperature inside the Bhunga based on the data for the experimental setup, such as pipe length (L) is 25 m, pipe internal diameter (d) is 12 cm, inlet air temperature ($T_i$n) = 35°C, soil temperature ($T_s$) = 20°C, air density (ρ) = 1.2 kg/m², air specific heat ($C_p$) = 1005 J/(kg·K), heat transfer coefficient of soil (U) = 4 W/(m²·K). The calculation summary of indoor air temperature ($T_i$) or outlet air ($T_o$ut) is attached with the manuscript for review reference.

**Experimental Result**

The research experiment yielded two main results. The first is from the mathematical model, and the second is a report on the indoor air temperature measured during a hot summer after setting up the pilot model on the ground. The mathematical model's results show how much heat the ground absorbs in a specific area, based on factors like heat transfer per unit length and area, air flow conditions (low, moderate, high), air density, and an exponent value. The summary of the indoor air temperature calculations is included in a separate sheet attached to this manuscript for reviewers. This summary shows that low air flow through the earth tube cools the air strongly, but moderate and high air flow do not cool the air sufficiently to meet the required level.

## CONCLUSION

The design, development, and construction of old Bhungas in Kutch district are remarkable examples of "Architecture without Architects." Their appearance, the materials used, and the methods of construction all meet the needs of the people, the local climate, and the culture. They follow natural principles, staying cool in summer and warm in winter, making them eco-friendly masterpieces of the region.

After the major earthquake in Bhuj in 2001 in the Kutch region, the new Pacca Bhunga was built using the traditional Bhunga architectural form. However, a significant error was made by using a mix of modern building materials throughout the structure, especially on the conical hexagonal roof made of Mangalore tiles. This decision did not consider the harsh desert weather of the area. Using the incorrect materials without considering the local climate made the inside of the building much hotter. Because of this, people had to use cooling systems, such as fans, coolers, and HVAC units, all year to stay comfortable. This consumes a substantial amount of energy and increases electricity bills. Therefore, it is important to use passive cooling in hot weather and passive heating in cold weather for the Pacca Bhunga to make it more sustainable and efficient.

Numerous passive cooling methods can help cool indoor spaces during hot seasons and warm them in cold seasons. The author chose one of these passive strategies, the "Earth Tube Heat Exchanger," because it provides good results, is easy to build and use, and is very cost-effective for all types of communities. This method works well with both old and new Bhungas. The calculations from the mathematical model showed that using an Earth Tube Heat Exchanger can keep homes cool in the summer and warm in the winter. It proved that achieving energy efficiency is now easier and forms the basic idea for passive houses and nearly zero energy buildings. The research output showed that using this method reduces the need for active cooling and heating systems, lowers energy use, improves living conditions, enhances health, moves closer to the zero-energy building concept, and supports green architecture without harming the environment.

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