International Journal of Architectural Engineering & Urban Planning, Volume 33, Number 4, 2023
DOI: 10.22068/ijaup.713

Research Paper

Regional Materials and Environmental Sustainability in Hot and Humid Climates: A Study on Boushehr's Vernacular Houses

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Received: January 2022, **Revised:** June 2023, **Accepted:** December 2023, **Publish Online:** December 2023

Abstract
The consideration of environmental sustainability has permeated both conscious and subconscious realms throughout history. In the context of Boushehr city's historical architecture from the Qajar period, a myriad of sustainable residential structures attuned to the regional climate, ensuring occupants' thermal comfort, are evident. This sustainability, devoid of adherence to a specific theoretical framework, adeptly caters to the pragmatic needs of the building users. The primary objective of this study is to conceptualize the historical architectural composition of Boushehr, focusing on materials, and to conduct a thermal assessment of two structures, one historic and the other contemporary, within the city. To achieve this goal, a comparative analysis of traditional and modern building materials in Boushehr was executed through the utilization of Ecotect and Energy Plus simulation software, complemented by extensive survey and on-site investigations. The findings of this analysis reveal that traditional building materials, beyond their inherent harmony with the regional climate, exhibit superior physical properties compared to their modern counterparts. While advancements in technology have enhanced the chemical and mechanical attributes of contemporary building materials over time, amalgamating the advantageous physical attributes of traditional materials renders the latter more environmentally sustainable. Despite the fact that rooms constructed with older materials exhibit a higher average monthly temperature than those utilizing modern materials, the diminished heating and cooling loads of the former contribute to positioning older residential structures as closer approximations to a more sustainable archetype.

Keywords: *Environmental sustainability, Vernacular architecture, Material, Houses, Energy plus.*

1. INTRODUCTION

Architecture, as an early manifestation of individual and collective life, reflects humanity's enduring quest to organize existence in harmony with the surrounding environment (Nakhaei & Taheri, 2015). Examining primitive shelters reveals an inherent human inclination to coexist with nature. Historical architectural endeavors, beyond aligning with cultural and social contexts, have consistently prioritized user comfort (Aly, 2011). The traditional structures within the historical fabric of Boushehr exemplify Iranian architecture's success in adhering to the principles of environmental sustainability. The construction methods, physical attributes, promotion of air circulation, and utilization of indigenous materials characterize the traditional buildings in Boushehr, obviating the need for cooling and heating apparatus during both hot and cold seasons. Contemporary challenges, such as global warming, shifts in individuals' heat tolerance, and technological advancements, have reshaped the dynamics of thermal comfort. The pervasive reliance on mechanical cooling devices has diminished heat tolerance, a

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concern that could be mitigated by embracing architectural practices reminiscent of the region's older structures. Central to this is the use of indigenous materials, a practice integral to the sustainability of these buildings. Consequently, this research delves into the exploration of sustainability concepts and sustainable materials, introducing the study area and its evolving characteristics over the past decade. The investigation scrutinizes two distinct architectural examples from the Qajar and contemporary periods, focusing on the materials employed. By employing Energy Plus software to analyze both quantitative and qualitative material data, this study identifies positive attributes in both historical and modern structures. Consequently, it proposes an optimal solution for utilizing materials that align with environmental and climatic sustainability principles.

2. LITERATURE REVIEW

2.1. Environmental Sustainability

The global discourse surrounding sustainability, defined as the capacity for enduring practices into the future, has garnered significant attention in recent years (Joseph, 2012). Despite a widespread acknowledgment of its importance, Gray (2010) notes a limited exploration of the intrinsic meaning of sustainability. At its core, sustainability is a straightforward concept emphasizing coexistence with natural resources, with a primary goal of diminishing resource consumption and minimizing the production of wastewater and waste (Chapman, 2005). Attaining sustainability necessitates a harmonized integration of social, economic, and environmental dimensions. Embracing overarching principles, sustainability strives not only to preserve the Earth but also to propose practical and viable solutions while upholding the inherent diversity of nature (Munier, 2005). In the context of sustainable design, there is a notable emphasis on environmental sustainability within the realm of architecture. This perspective posits that sustainable buildings should exert the least adverse impact on the natural environment throughout their lifecycle. Many strategies advanced by sustainable architecture inherently incorporate climatic considerations. In this vein, human comfort is paramount, and climatic conditions play a pivotal role. Sustainable architecture integrates a multitude of factors, including climate, utilization of indigenous materials, cultural influences, and lifestyle considerations, among others, to shape the final structure. The objective is to create a built environment where occupants experience a comfortable atmosphere while simultaneously receiving positive messages within the space (Memarian, 2017).

2.2. Sustainability and Vernacular Architecture

The exploration of sustainability involves examining the intricate relationship between humanity and the natural environment. Although sustainability is a multifaceted concept, the environmental aspect has received heightened attention over the past three decades, emphasizing the imperative to conserve nature and safeguard the environment (Giovannoni & Fabietti, 2013). Despite its global significance, the foundations of sustainability are deeply embedded in indigenous and regional knowledge, reflecting a localized perspective (Kirby, 2008). The principle of "Think Globally, Act Locally" advocates for an environmentally conscious approach to sustainability, a concept that extends to the field of architecture as well (Powell, 2012). Indigenous architecture stands out as a form characterized by inherent sustainability in terms of energy usage, material selection, and reliance on regionally sourced resources (Edwards, 2008). Functioning as a historical adaptation of regionalism, indigenous architecture aims to preserve, maintain, renovate, and repurpose traditional patterns, breathing new life into past architectural styles. This encompasses various forms such as stylistic, revitalizing, empirical (folk architecture or architecture without architects), romantic regionalism, neo-environmentalism, and conservative environmentalism (Heath, 2009). Lacking a specific theoretical framework and often neglecting aesthetic considerations, indigenous architecture fosters a symbiotic relationship with the site and surrounding environment, serving as the preferred architectural choice for indigenous communities within the region. This human-made architecture, to a significant extent, mirrors the natural surroundings and generally lacks a predefined plan. In essence, these structures are devoid of a designated architect and employer; each individual assumes the roles of both for their own dwelling (Rapoport, 2008). The dichotomy between indigenous and formal architecture serves as a prominent index, with the former distinguished by its simplicity, popularity, and responsiveness to the general population's needs. Indigenous architecture diverges from the pursuit of modernization, with its patterns remaining largely unaltered, drawing inspiration from traditional buildings and construction methods of the distant past (Rudofsky, 1965). Traditions occupy a distinctive position in indigenous architecture, as different human groups, shaped by diverse attitudes and ideas, manifest unique reactions to their environment. This diversity is reflected in the varied architectural expressions that encapsulate the cultural essence of a region, as argued by Rapoport (2008).

2.3. Sustainability and Vernacular Materials

In the realm of sustainability, materials possessing specific attributes are deemed favorable. These characteristics include low energy consumption and minimal pollution generation (Zimmermann et al., 2005; Calkins, 2008), ensuring they do not inflict harm upon the environment (Wever, 1997). Desirable materials are sourced from renewable primary resources, exhibit lower consumption of primary resources, energy, and water (Calkins, 2008), and necessitate the extraction of fewer raw materials (Kim & Rigdon, 1998). Additionally, they boast high durability to enhance the longevity of the building (Godfaurd et al., 2005; Isik, 2008), possess non-toxic and non-carcinogenic properties, contribute to noise prevention, and generate minimal waste (Zhou et al., 2009; San-Jose et al., 2009; Calkins, 2008). The materials of interest are characterized by low production costs (Veese et al., 2009) and do not contribute to pollution during production and recycling (Howarth & Hadfield, 2006). They play a role in reducing energy consumption throughout the building's utilization phase (Morel et al., 2001; Lyons, 2010; Zimmermann et al., 2005). Furthermore, they exhibit the ability to be recycled in nature, avoid the production of non-recyclable waste, and offer possibilities for reuse (Calkins, 2008; Yagi and Halada, 2001; Wever, 1997). The materials in question should also facilitate repairs during utilization (Yagi and Halada, 2001) and be compatible with existing manufacturing technology, requiring no advanced machinery (Veese et al., 2009).

Indigenous materials encompass resources that are either readily available within the city or village where construction takes place or are procured from nearby regions in close proximity. Dr. Pirnia, as cited by Memarian (2017), introduces the term "region-derived" to characterize materials that signify self-sufficiency based on the five criteria intrinsic to Iranian architecture: endogeneity, avoidance of frivolity, humanization, self-sufficiency, and geometry. Over time, historical buildings in Iran, particularly numerous residential structures, persist as resilient and habitable entities. The materials employed in these constructions not only afford physical comfort to occupants but also align with the concept of being "region-derived." Frequently unprocessed, these materials are deemed sustainable due to their latent energy, absence of contamination, and minimal environmental impact (Kim & Rigdon, 1998).

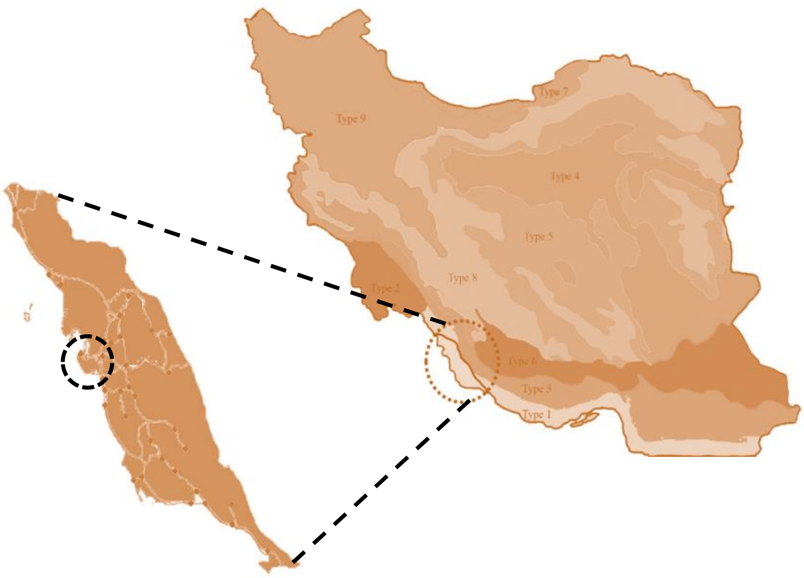
3. BOUSHEHR OVERVIEW

3.1. Climate

The climatic zoning of a geographic region, including a country, is determined by various factors such as climate, radiation angle, temperature, precipitation, and more (Walsh et al., 2017). Iran is categorized climatically into different regions, with global recognition of classification schemes by Coupon (1931) and Thornthwaite (1948) (Heidari & Alijani, 1999). Additionally, the Geological Organization and the National Geoscience Database have divided the Iranian territory into seven climatic zones based on seasons. Engineer Morteza Kasmaei, in his influential work, further refined climatic classification in Iran, assigning nine climatic zones, a classification commonly used in architectural studies (Kasmaei, 2015). Table 1 provides an overview of these nine zones, and Picture 1 illustrates their distribution on the map of Iran. Figure 1 offers a comparative analysis of maximum summer temperatures and lowest winter temperatures across these nine climates. As depicted in the figure, Iran is situated in a relatively warm and temperate region globally. The city under study in this research, Boushehr, falls into the first group, characterized by warm summers and a very humid climate with minimal winter conditions.

Boushehr, situated in the warm and very humid climate zone of Iran, is positioned between 50°6′ and 52°58′ latitude, with an elevation of 9 meters above sea level (Habibi, 2012). The region's climate is influenced by factors such as its low latitude, proximity to the sea, the prevalence of wet and warm sea winds, and the impact of the Sudanese and Mediterranean cyclones during autumn and winter (Moshiri, 2009). Notable features of the climate include minimal variations in annual temperature, intense sunlight, elevated relative humidity, and a negligible decrease in temperature following rainfall. According to data from the Weather Bureau of Boushehr (Givoni, 1976), the highest and lowest temperatures recorded over the ten-year period from 2007 to 2017 occurred in August, reaching 46°C, and in February, dropping to 3°C, respectively (Figure 1). The proximity of the minimum and maximum temperature curves underscores the region's characteristic of relatively low temperature fluctuations at night, a significant attribute of warm and humid climates. Figure 3 presents the monthly rainfall patterns for the same ten-year period, indicating that the highest rainfall, occurring in January, reached 170 mm, while negligible rainfall was observed from June to October. Rainfall in Boushehr predominantly transpires during the colder seasons, at times being substantial and leading to flooding. During such occurrences, underground water levels swiftly rise, facilitated by Boushehr's coastal location.

Figure 4 illustrates the minimum and maximum relative humidity data for the ten-year span from 2007 to 2017. The highest relative humidity is observed in January, reaching 95%, while the lowest occurs in May, approximately at 33%. The consistently high relative humidity throughout the year is a clear indication of the influence of coastal humidity, a significant characteristic of the region. The prevailing winds in the city predominantly originate from the west and northwest, and mild sea breezes are perceptible across all seasons. Additionally, Figure 5 depicts that the Leymer wind, with a northwest-southeast direction, is the dominant wind in this area. The openings within the urban fabric are not oriented in a singular direction, as gentle sea breezes come from all sides. These openings are strategically aligned with the prevailing winds and sea breezes. Consequently, all directions along the edges of the urban fabric, particularly those adjacent to the sea, are considered suitable for openings.



Picture 1. Iran's climatic zoning map and the location of Boushehr

Table 1. Climate zoning of Iran (Kasmaei, 2015)

Climate type	Features: summer	Winter	Average maximum summer temperature (C°)	Average winter temperature (C °)	Examples in the climate zone
1	Warm and too wet	No winter	35-40	10-15	Jask, Chabaha, Bushehr, Bandarabbas
2	Too warm and wet	No winter	45-50	5-10	Abadan, Ahvaz
3	Warm and wet	Moderate	35-40	0-5	Kazeroon
4	Too warm	No winter	40-45	5-10	Iranshahr
5	Too hot and dry	Moderate	40-45	0-5	Tabas, Kashan
6	Moderate and humid	Moderate	25-30	0-5	Babolsar, Anzali port, Rasht, Gorgan
7	Warm and dry	Moderate	35-40	0-5	Zabol, Zahedan, Fasa, Bam
8	Warm and dry	Cold	35-40	0-5	Tehran, Shiraz, Mashhad
9	Warm and dry	Too cold	35-40	5-10	Arak, Hamedan, Zanjan, Tabriz

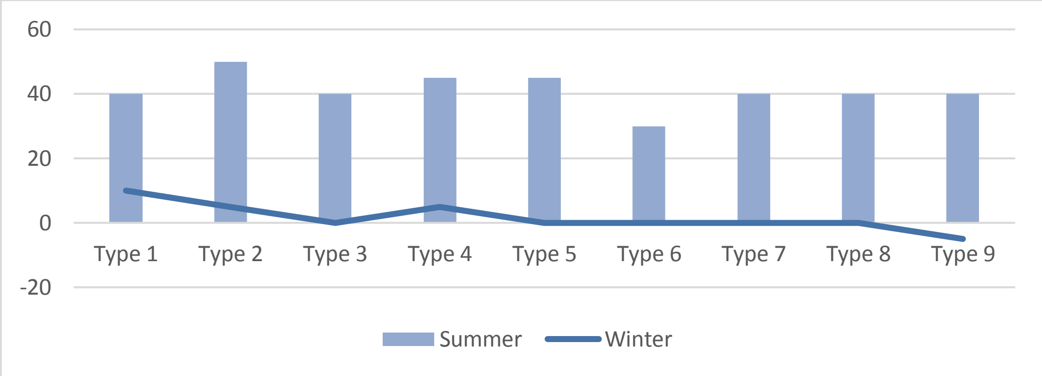


Fig 1. Comparison of maximum summer temperatures and minimum winter temperatures in Iran's climate (Boushehr Weather Bureau, 2020)

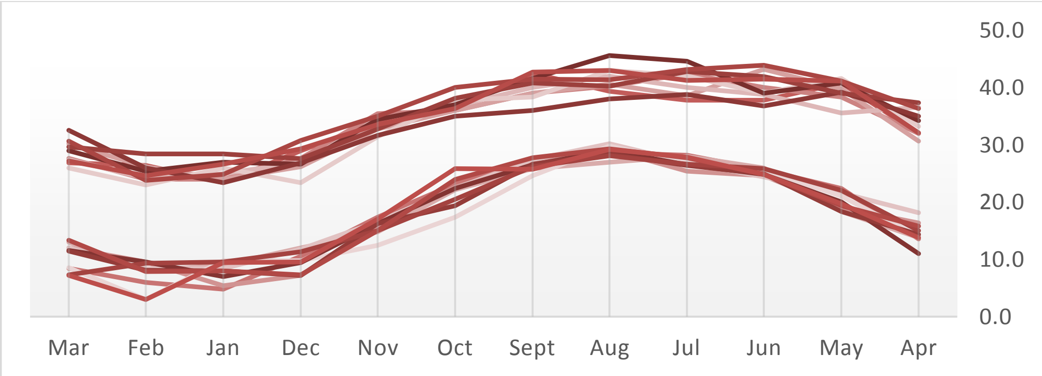


Fig 2. Maximum and Minimum temperature recorded in 10 years (2009-2019) in degrees centigrade (Boushehr Weather Bureau, 2020)

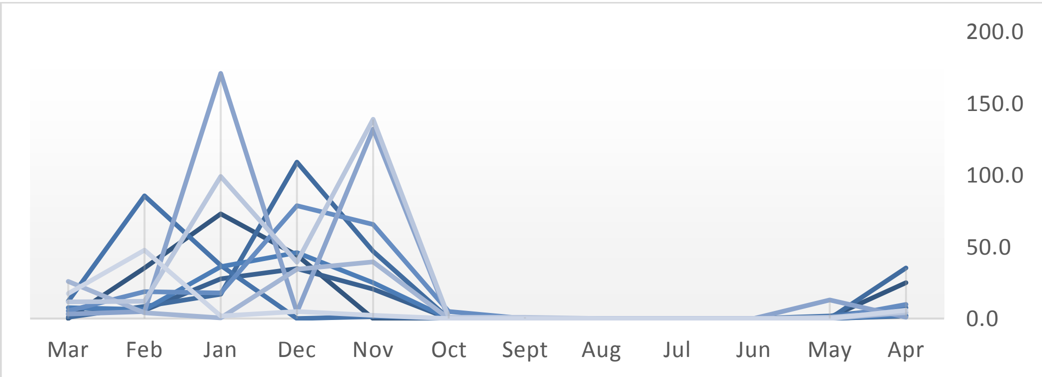


Fig 3. Monthly rainfall recorded in 10 years (2009-2019) in millimeters (Boushehr Weather Bureau, 2020)

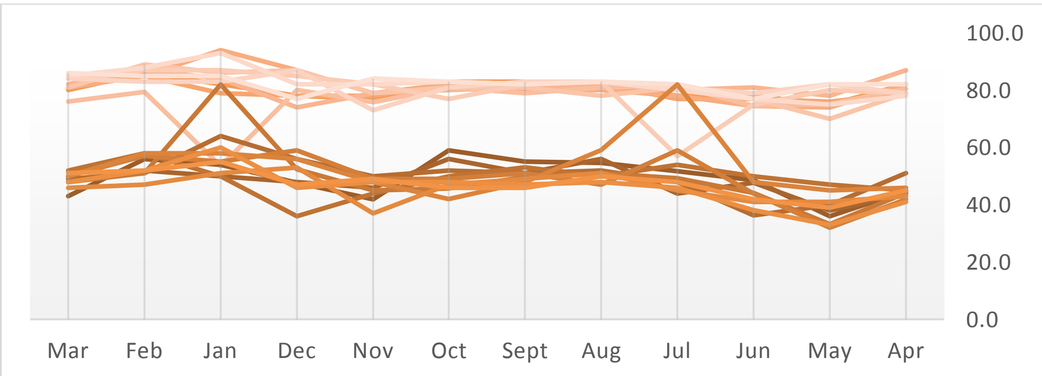


Fig 4. Maximum and minimum relative humidity recorded in 10 years (2009-2019) in percent (Boushehr Weather Bureau, 2020)

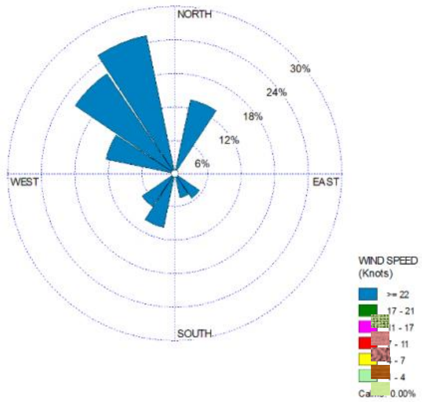


Fig 5. Windrose of Bushehr province recorded in 2019 (Boushehr Weather Bureau, 2020)

3.2. Architecture

The Boushehr peninsula, situated on the periphery of the Persian Gulf, holds a rich history, dating back 5,000 years, making it one of Iran's foremost ports. The name "Boushehr" translates to "Bukht Ardashir," signifying the city of salvation and the place where Ardashir was saved. This city is attributed to Ardashir Babakan, the inaugural Sassanid king, who constructed it as part of a series of cities around the Persian Gulf (Hamidi, 2005). Previously known as Lian in the second millennium BC during the Ilam civilization (Yahosseini, 2008), the historical fabric of Boushehr comprises four neighborhoods in the northwest and several smaller neighborhoods in other parts of the city (Sadidosaltane Bandarabbasi, 2007). Notably, the northwest neighborhoods—Behbahani, Shanbedi, Dehdasti, and Kouti—house the majority of historically significant monuments in Boushehr (Ahmadi Rishehri, 2001).

The strategic geographical positioning of the historic fabric of Bushehr along the shoreline has imparted distinctive architectural features to the monuments in this region. Given Bushehr's warm and humid climate, the old urban fabric exhibits a compact and contiguous layout, with due consideration to climatic factors in both building design and urban development. The integration of the cool sea breeze into the urban fabric, coupled with the imperative of creating open spaces around the houses to facilitate air circulation, has influenced the subdivision of Bushehr's historic fabric into the smallest feasible blocks (Shahin & TakapooMensh Baghaei, 2006). In these neighborhoods, the urban fabric is notably dense, characterized by narrow alleys not exceeding a maximum width of 1 to 1.5 meters. The ratio of wall height to alley width is approximately ten to one, and the alignment of buildings often follows the direction of the prevailing sea winds. The construction of tall buildings, coupled with the orientation of passages and structures toward the sea, not only casts shadows in these narrow alleys but also diminishes ambient temperatures while facilitating the flow of seaside breezes (Ghobadian, 2006). The winding alleys originate from one square, progress through multiple squares, and eventually lead to the waterfront (Picture 2). This irregular yet systematically planned network maximizes the cooling effect of gentle sea breezes as they pass through the openings of Shenashirs and windows. Consequently, the pleasantly cool air permeates penthouses, vestibules, and lofts within the structures (Hamidi, 2005).

The buildings and residences in the city either lack a courtyard or feature a central yard (surrounded by rooms and halls), or alternatively, the yard is situated in the front or rear with rooms on one side of the structure. In all cases, these buildings incorporate a water storage facility (Hamidi, 2005). The upper floors were designed to be cooler than the lower ones. In residential buildings, occupants typically resided on the upper floors, while commercial structures housed offices on the top floor. The orientation of porches and building doors was typically towards the Qibla (west), allowing residents to benefit from morning breezes and shadows. The architectural elements of cube-like volumes, central courtyard enclosures, and expansive porches with extended ceilings and wooden walls in Boushehr's historic architecture served to minimize horizontal surfaces and ceilings, thereby mitigating heat absorption from solar radiation (Shahin & TakapooMensh Baghaei, 2006). The construction and layout of these buildings were meticulously designed to ensure that residents experienced reduced discomfort and heat during hot summer days. Table 2 outlines the key principles of indigenous architecture tailored to the warm and humid climate of Boushehr.

Picture 2. Boushehr old fabric

Table 2. The general principles of vernacular architecture of the warm and humid area (Nadoomi, 2016)

Climate	Material	Plan Type	Material color	Number of windows	Roof type	Orientation of buildings	Building type
Hot and humid	Low heat capacity	Wide	Bright	Medium	Flat	South to the south east	Pilots

3.3. Materials

As previously mentioned, region-derived materials, whether in their raw or processed forms, are those extracted from the region itself or its closest vicinity. In contemporary construction practices, the combination of materials to enhance their properties has become unavoidable, rendering the use of solely region-derived materials nearly obsolete. Nevertheless, the materials found in traditional fabrics offer valuable insights for the present era. These fabrics represent a distinct form of authentic architecture that, despite economic limitations, scarce energy resources, unfavorable site conditions, varying climates, and the cultural and social needs of the past, were crafted to address the fundamental survival requirements of their inhabitants while also meeting complex and diverse needs (Edwards, 2014). The techniques and materials employed in different regions of Iran are primarily shaped by the geographical environment. Human ingenuity has been most effectively harnessed to utilize local resources in the construction of structures and their facades (Mohammad Moradi & MohebAli, 2017). In the context of Boushehr, the materials prevalent in most buildings include porous stone, plaster, sarooj, chandal beam, wood, cast iron, loose mortar, bolyow, soil, and glass.

Porous limestone, known as Gassar, plays a pivotal role in the construction of traditional building walls in the Boushehr port. These regionally derived rocks are primarily composed of coral and sedimentary deposits from the sea, forming the main constituents of traditional building walls. Located just a few meters beneath the surface in a broad layer, these rocks are readily accessible (Ghobadian, 2014). Porous limestone is extensively utilized in constructing foundations, walls, pillars, lintels, and courtyard floor pavements. When used in an ordered and shaped form in the lower floors, it is referred to as "shemsh" or "shemsh." This type of stone is created from scallop and compacted sand that settles on the rocky terrain's surface after the withdrawal of seawater. Notably, the durability of porous limestone surpasses that of any type of brick or adobe. Following the demolition of a building, the rocks can be confidently repurposed in the construction of another building. It's important to distinguish between two types of these materials: the strong type utilized in building structures, and the soft type (Tesk), which lacks the durability of the former and is employed as filler in areas not requiring load-bearing capabilities.

Plaster; plaster is used in the outer surface of the building, interior decoration, between the columns, flooring and in the building decoration.

Sarooj; sarooj, a construction material, is formulated by blending sifted clay with hydrated lime and adding water to the mixture. Once the blend is thoroughly saturated, it undergoes a kneading process and is subsequently employed as mortar for constructing foundations, walls, and the skeletal framework of buildings. Sarooj, characterized by its robust composition, serves as a substantial construction material, serving as an alternative to contemporary cement. It was conventionally utilized in areas of a building that came into direct contact with water, such as the surfaces of water storage rooms (cisterns) and ponds. Additionally, it was applied to the walls up to a height of 1 meter to deter moisture. Notably, Sarooj exhibits a distinctive copper-red hue and boasts superior strength compared to cement. Remarkably, structures and water storage rooms constructed with Sarooj remain resilient even after 250 years since their initial construction.

Chandal beam; a wooden beam specific to the ceiling that was brought from India or Africa. Possessing impressive strength and demonstrating durability exceeding 200 years, chandal beams were predominantly employed to cover ceilings in various spaces, including rooms, corridors, and porches. These beams were also horizontally laid across two walls to establish a robust connection between them, enhancing the overall structural integrity of the construction. The utilization of load-bearing chandal beams was particularly effective in covering entire ceilings due to the broad dimensions of the openings and the relatively short lengths of the beams, providing essential structural support (Gholam Zade, 2013).

Wood; wood has been a luxurious material in Iran from ancient times until today due to its scarcity. Wood is predominantly utilized in architectural embellishments, serving decorative purposes in elements such as sashes, ornamental arches, handrails, and entrance doors. The Orosi, a term derived from the Russian language signifying "open" (Hamidi, 2005), refers to a courtyard-facing window that opens upwards, characterized by diverse dimensions and sizes, typically featuring both fixed and movable components, commonly known as a sash window (Gholamzade, 2013). Decorative arches find extensive application in chambers and above windows, serving as embellishments to enhance the aesthetic appeal of guest spaces. The term "Mahjar," borrowed from Arabic, designates rails positioned along the edges of porches and openings (Ahmadi Rishehri, 2001). These rails serve dual purposes, ensuring safety and contributing to the overall aesthetic beauty of the facade in various forms.

Cast iron; it is used in the window bars, *shenashirs*, handles, and fittings. In specific instances, such as entry doors, metal is employed not only for its functional role as a handle or knocker but also decoratively as studs. The choice of metal, particularly cast iron, is meticulous, aiming to withstand the sulfates present in water and air. The longevity of cast iron surpasses that of other metals, making it a preferred material for applications where durability against environmental factors is paramount (Shahin & TakapooManesh Baghaei, 2006).

Loose mortar or *sholeh*; in the old fabric, the roof was covered with a material called *shol* that worked like mud overlay and prevented the penetration of moisture into the lower layers of the ceiling. This mortar has also been used to prevent moisture penetrating materials (Mohammad Moradi & MohebAli, 2017).

Bolyow; it originates from the local dialect of Boushehr, refers to a cane. The primary constituent of the material under investigation is a prevalent marsh reed species, abundantly distributed in the lakes, riverbanks, and wetlands of the locality. This material demonstrates noteworthy resistance to mold, mildew, and moisture, as documented by Tanaka, et al, 2016. The substance in question, comprising a woven cane or reed, served multifunctional purposes such as matting and ceiling and wall coverings (intended to mitigate exposure to westward light). Additionally, it was occasionally crafted from palm leaves. Notably, the material is predominantly woven from split marsh reeds, either halved or in their entirety, fastened together in a singular row through the utilization of cotton thread. Significantly, contemporary applications persist, with bolyow continuing to be employed for both decorative and utilitarian purposes in a majority of residences within this locale.

Soil; the soil used in this region comes from a place called *Poodar*. It has been the raw material for the preparation of *sarooj*. The soil is cooked for a week, then it is shaped into mud bricks to be used after drying (Gholam Zade, 2013).

Glass; in Boushehr architecture, glass is an effective element from the practical and aesthetic aspects. The glass employed in this geographic area, akin to numerous other native structures in Iran, manifests itself in the configuration of "colorful cups," distinguished by shades of blue, ruby, lemon, and green (Zomarshidi, 2010). This particular glass variant, beyond its role in managing sunlight penetration, serves as a deterrent against pests and insects. The composition of this glass involves a blend of distinct elements: "cobalt" imparts the blue hue, "gold" contributes to the ruby coloration, "selenium" bestows the lemon tint, and "chromium" is instrumental in achieving the green hue.

4. METHODOLOGY

This research is a case study of the fundamental-exploratory type. In the first stage, the meteorological data for the past 10 years was received from the Boushehr Meteorological Office (2020). Meteorological time and weather data including year, month, day, hour, wind direction, wind speed and a number of winds with a specific speed were used to draw of the 'wind rose' using the WRPLOT View software (Jesse et al, 2016). Based on the obtained data, this study was conducted using survey and simulation research methods by Ecotect and Energy Plus software. Non-random sampling method was used to select two residential buildings in Boushehr. The cartography of an older residential structure was conducted through on-site field study and visits, while the blueprint for a new building was obtained from the engineering office. Energy Plus software, developed by experts from the University of Illinois and California in collaboration with entities such as the US Energy Department and the US Army Engineering Unit, serves the purpose of simulating the thermal performance of a building's walls. Recognized as a prominent tool for building simulation and energy analysis, this software possesses the capability to calculate or, more precisely, "predict" diverse variables associated with building energy consumption throughout the year. This predictive capacity is contingent upon the physical attributes of the building, the characteristics of its inhabitants, equipment specifications, "hourly" climatic data, and the specific features of the building site. Exemplary variables within this predictive framework include air and surface temperature, heat transfer from both opaque and transparent surfaces, as well as the assessment of heat and cold loads within the building (Tahmasebi & Kari, 2009).

This research takes into account various parameters that influence the energy consumption of the examined buildings, encompassing factors such as building orientation, architectural design, dimensions, and the materials utilized in transparent walls. The nature of the building material is treated as the independent variable, with energy consumption serving as the dependent variable. Subsequent to the selection of both old and new residential structures, input data for simulation was gathered through a comprehensive survey. The equipment and devices within the spaces were meticulously documented and defined for the buildings under investigation. Consequently, variables such as the type and dimensions of windows, building form, orientation, and location, along with the number of users, duration of occupants' presence in the building, and specifics of the equipment, were incorporated as control variables in the simulation process.

The building models were created using Ecotect and subsequently integrated into Energy Plus as a test model. Within Energy Plus, the technical specifications of the building were delineated in accordance with the existing conditions and recorded data. Subsequently, a program detailing the utilization of space equipment, an hourly activity schedule, as well as the timing and extent of human presence were specified for Energy Plus. The ensuing steps involved in modeling the building focus on examining the impact of different material types on energy consumption:

1- Preparing a volumetric model of the building in the interface software (Ecotect)

2- Defining the properties of the building under study and its conditions, such as: Determining the materials of the opaque and transparent walls.

3- Defining people's presence schedule

4- Defining clothes coverage rate and activity type program

5- Defining the program of using electrical equipment and their consumption rate

6- Defining the program of lighting equipment usage and their consumption rate

7- Analyzing the data obtained by the software. The epw file related to weather data of Boushehr, in which weather data is recorded hourly, was used to simulate the thermal performance of the model prepared based on the climate of Boushehr. This file is one of several climatic files of Iran approved by the Energy Plus developers and is available on the website of the software providers[1]. Finally, the output of the building in terms of cooling and heating was recorded for 12 months for each floor and the data were compared.

5. DISCUSSION AND RESULTS

5.1. Analysis of Materials in Boushehr's Old Fabric Buildings

As asserted by Forootani (2017), materials exhibit diverse properties, encompassing physical, chemical, mechanical, and aesthetic characteristics. The general physical properties of materials are further categorized into four distinct groups: fundamental material information, the impact of water and moisture on materials, responses to thermal changes such as those occurring in fire, and the physical interaction of materials with light, sound, and electricity (Sartipi Pour, 2013). Chemical properties, on the other hand, pertain to a material's resistance to external elements, including acids, bases, salts, and gases. The mechanical properties of materials are contingent upon their capacity to withstand external forces, encompassing considerations such as force, resistance, hardness, and deformation (Dowling, 2013).

The architectural characteristics of materials are intricately linked to both indigenous and personal aesthetic principles. Each material possesses its own

[1] www.energy.gov

unique blend of beauty and functional attributes. The successful coordination of materials with interior and exterior architectural spaces, alignment with the intended functions of the structure, balance with the surrounding environment, and the adept combination with other materials or the selection of appropriate dimensions and sizes for each material underscore the architect's ability to bring their vision to fruition. As articulated by Forootani (2015), the transition from the design phase to actual construction demands that architectural engineers wield creative prowess, experience, and a comprehensive understanding of the scientific and technical aspects related to building elements. The indigenous materials native to Boushehr not only exist in abundance but also harmonize seamlessly with the warm and humid climate of the region. Beyond possessing physical, chemical, and mechanical attributes, these materials have effectively met the climatic and aesthetic requirements of the city's historical fabric, owing to their region-specific properties. The qualitative and quantitative characteristics of these materials, as previously elucidated, are shown in Tables 3 and 4.

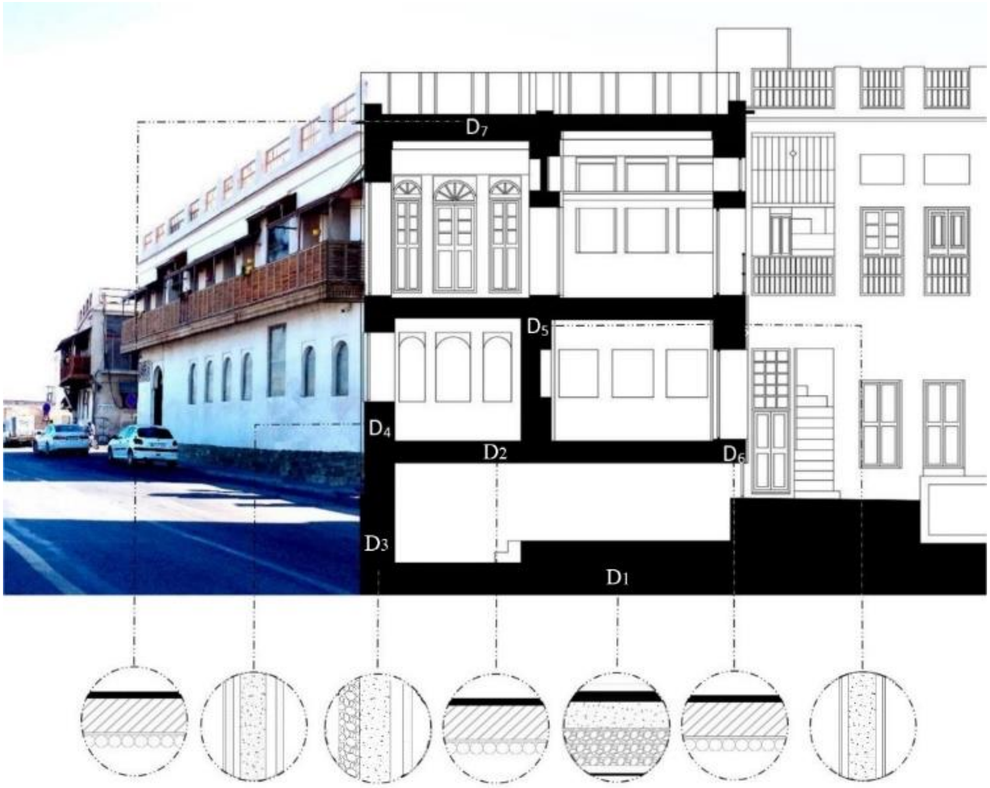
In the historic fabric of Boushehr, encompassing residential, commercial, religious, and diplomatic structures, a consistent use of indigenous materials is observed. Notably, the facades exhibit a standardized appearance, irrespective of the diverse functions and purposes served by these buildings. This uniformity in visual presentation underscores a lack of visible differentiation based on socioeconomic levels, serving as a tangible manifestation of social and environmental sustainability (see Picture 2). Picture 3 offers a cross-sectional depiction of an aged building, illustrating various configurations arising from the combination of three fundamental building elements: floor, wall, and ceiling. The juncture of these elements is delineated in seven distinct modes denoted as D1 to D7 in Table 5. These modes encompass the basement floor, ground floor, upper stories floor, the wall between two interior spaces, the wall separating the interior and exterior, basement wall, and ceiling. According to Table 5, the thickness of the floor ranges from 85.5 to 145 cm, the wall measures between 67 and 112 cm, and the ceiling spans 85.5 to 115.5 cm. Additionally, Table 6 details the physical, chemical, and mechanical properties corresponding to each of these architectural configurations.

Table 3. Qualitative properties of materials used in the old fabric of Boushehr (Nadoomi, 2016)

Material type	Texture	Color	Disposal of moisture	Heat capacity	Weight	Restoration ability	Flexibility in use
Coral reef	Obscure	Bright	Yes	Suitable	Light	Yes	Yes
Plaster	Obscure	Bright	Yes	Suitable	Light	Yes	Yes
Sarouj	Obscure	Dark	No	Unsuitable	Light	Yes	Yes
Chandal	Obscure	Dark	No	Suitable	Light	No	Yes
Wood	Obscure	Dark	No	Suitable	Light	No	Yes
Cast iron	Polished	Dark	No	Unsuitable	Heavy	No	Yes
soil and water mortar	Obscure	Bright	Yes	Suitable	Light	Yes	Yes
Bolyow	Obscure	Bright	Yes	Suitable	Light	Yes	Yes
Soil	Obscure	Bright	Yes	Suitable	Light	Yes	Yes
Glass	Polished	Various	No	Suitable	Light	-	Yes

Table 4. Quantitative properties of materials used in the old fabric of Boushehr

Material type	Features							
	Physical				Chemical		Mechanical	
	Specific gravity Kg/m^3	*Thermal* Conductivity W/m C	Thermal resistance mc/w	melting point	Resistance to acids	Resistance to bases	Tensile strength	Compressive strength
Coral reef	26	0.12	8.83	-	High	High	-	415-170
Plaster	1442	0.48	2.08	125	Low	Low	-	6
Sarouj	1900	_	_	_	High	High	_	_
Chandal	769	0.16	6.25	-	Low	Low	110-20	-
Wood	769	0.16	6.25	-	Low	Low	110-20	-
Cast iron	7150	57	0.0176	1350-115	High	High	110-20	-
soil and water mortar	2000	0.5	-	-	-	-	-	-
Bolyow	-	0.16	6.25	-	Low	Low	110-20	-
Soil	2100	-	-	-	-	-	-	-
Glass	1520	1.04	0.98	1500	High	High	172-34	-



Picture 3. A section of a typical Building in old fabric of Boushehr

Table 5. The layers of materials used in different situations in roof, wall, and floor encounter in a sample of an old building in Boushehr

Feature	Type	Location	Layers	Layer thickness cm	Total thickness cm
Floor	D_1	Second basement	Lime mortar	15-10	175-145
			Root rock linking foundation with base course	20	
			base course	50	
			Soil (sand) filler materials	70-50	
			soil and water mortar	15-10	
			Sarooj mortar	5	
	D_2	Floors	Chandal (Lumber)	25-20	115.5-85.5
			Board	5	
			Bolyow	0.5	
			Soil (sand) filler materials	70-50	
			soil and water mortar	15-10	
Wall	D_3	Second basement	Coral reef	-	92-67 (Excluding stone)
			Structural wall	70-50	
			soil and water mortar	15-10	
			Sarooj mortar	5	
			Plaster	2	
	D_4	External	Sarooj mortar	5	112-82
			soil and water mortar	15-10	
			Structural wall	70-50	
			soil and water mortar	15-10	
			Sarooj mortar	5	
			Plaster	2	
	D_5	Internal	Structural wall	70-50	92-67
			soil and water mortar	15-10	
			Sarooj mortar	5	
			Plaster	2	

Feature	Type	Location	Layers	Layer thickness cm	Total thickness cm
Ceiling	D_6	Ceiling-Floor	Chandal (Lumber)	25-20	115.5-85.5
			Board	5	
			Bolyow	0.5	
			Soil (sand) filler materials	70-50	
			soil and water mortar	15-10	
	D_7	Roof	Chandal (Lumber)	25-20	115.5-85.5
			Board	5	
			Bolyow	0.5	
			Soil (sand) filler materials	70-50	
			soil and water mortar	15-10	

Table 6. Features of different states of roof, wall and floor collisions of an old building in Boushehr

Location	Type	feature							
		Physical				Chemical		Mechanical	
		Specific gravity Kg/m^3	*Thermal* Conductivity W/m C	Thermal resistance mc/w	melting point °c	Resistance to acids	Resistance to bases	Tensile strength N/mm^2	Compressive strength N/mm^2
floor	D_1	7952	0.24	17.66	-	High	High	-	170-415
	D_2	1538	0.32	12.5	-	Medium	Medium	20-110	-
wall	D_3	5368	0.6	17.66	125	Medium	Medium	-	176-421
	D_4	7952	0.24	17.66	-	High	High	-	170-415
	D_5	5368	0.6	17.66	125	Medium	Medium	-	176-421
ceiling	D_6	1538	0.32	12.5	-	Medium	Medium	20-110	-
	D_7	1538	0.32	12.5	-	Medium	Medium	20-110	-

5.2. Analysis of Materials in Boushehr's Contemporary Buildings

The evolution of architecture in Boushehr over the centuries has witnessed a notable inclination towards embracing global building systems, particularly modern materials. Consequently, an investigation into these contemporary materials employed in today's structures within this climate, and their juxtaposition with traditional counterparts, serves to delineate their merits and drawbacks. In the present era, architects, influenced by economic, climatic, and structural considerations, among others, no longer confine themselves to a singular construction approach. Boushehr is reflective of this trend. According to the Engineering Organization's 2021 statistics, in 2020, 93% of buildings in the region employed a concrete structure, with only 7% featuring a metal structure and load-bearing walls. The utilization of concrete is attributed to its resilience against the region's elevated humidity, which can reach up to 90% owing to its proximity to the sea. Moreover, the certified facades in the region, as per the same statistics, predominantly consist of materials such as travertine, granite, ceramic, aluminum, and brick. Notably, 86% of approved facades in the organizational maps are constructed using stone. The decline in the use of aluminum composite and bricks can be attributed to aluminum's susceptibility to corrosion in moist environments and the absence of porosity in bricks to facilitate moisture disposal. However, there is a current resurgence in the use of wood and white cement alongside stone in facades, reflecting the population's inclination towards traditional aesthetics. Consequently, the number of buildings adopting this approach is on the rise. The examination of various building systems and materials, as detailed in Tables 7 and 8, contributes to a comprehensive understanding of new materials. However, for the calculation of heating and cooling loads in buildings, only the building system and materials used in the specific case study (a new residential building) were considered. Nevertheless, the information was juxtaposed with that of buildings in the historic fabric of the region, constructed using indigenous materials.

Table 7. The layers of materials used in different situations in roof, wall, and floor encounter in a sample of a contemporary building in Boushehr

Feature	Type	Location	Layers	Layer thickness cm	Total thickness cm
floor	Basement		Terrazzo Tile	1	Min 103
			Cement mortar	2	
			Flooring cement (200kg/m^3)	10	
			Hard core	Min 90	
	Floors		Terrazzo Tile	1	73.42-68.42
			Cement mortar	2	
			Concrete foam	13	
			Rebar	3	
			Concrete hollow block/Styrofoam block	25-20	
			Runner	25	
			Metal lath	0.12	
			Gypsum plaster	5.1	
			Veneer plaster	0.2	
Wall	Internal		Veneer plaster	0.2	20.6
			Gypsum plaster	5.1	
			Concrete or brick block	20	
			Gypsum plaster	5.1	
			Veneer plaster	0.2	
	External	Brick facade	Veneer plaster	0.2	39.3
			Gypsum plaster	5.1	
			Concrete or brick block	20	
			Cement mortar	2	
			Brick facade	11	
		Cement facade	Veneer plaster	0.2	39.6
			Gypsum plaster	5.1	
			Concrete or brick block	20	
			First layer	1	
			Second layer	1	
			Gunite	0.3	
		Thermo wood facade	Veneer plaster	0.2	31.6-31.1
			Gypsum plaster	5.1	
			Concrete or brick block	20	
			Structural tubing	3	
			Substructure wood	2.5	
			Thermo wood facade	-0.50.3	
		Stone facade	Veneer plaster	0.2	33.3-28.3
			Gypsum plaster	5.1	
			Concrete or brick block	20	
			Cement mortar	2	
			Stone facade	5-1	
Ceiling	Ceiling-Floor	Runner-foam	Terrazzo Tile	1	74.15-69.15
			Cement mortar	2	
			Concrete foam	13	

Feature	Type	Location	Layers	Layer thickness cm	Total thickness cm
			Rebar	3	
			Concrete hollow block/Styrofoam block	25-20	
			Runner	25	
			Metal lath	0.12	
			Gypsum plaster	5.1	
			Veneer plaster	0.2	
		Cobiax	Terrazzo Tile	1	69.3
			Cement mortar	2	
			Concrete foam	13	
			rebar Top	4	
			Hollow balls	40	
			rebar Bottom	4	
			Gypsum plaster	5.1	
			Veneer plaster	0.2	
	Roof		Mosaic	5	63.7-58.7
			Cement mortar	2	
			Moisture insulation	0.4	
			Slop concrete	1	
			Structural roof	50-45	
			Gypsum plaster	5.1	
			Veneer plaster	0.2	

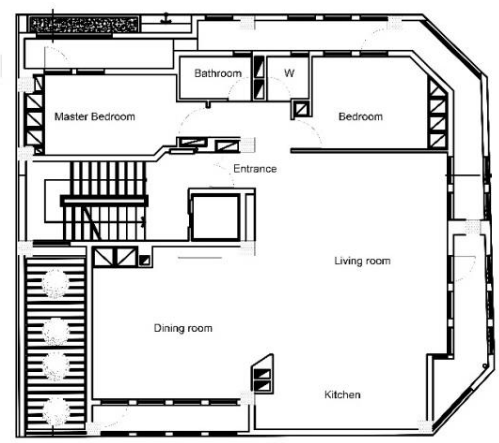
Table 8. Features of different states of roof, wall and floor collisions in a contemporary building sample

Space type	Location	Type	Features							
			Physical				Chemical		Mechanical	
			Specific gravity Kg/m^3	*Thermal* Conductivity W/m C	Thermal resistance mc/w	melting point °c	Resistance to acids	Resistance to bases	Tensile strength N/mm^2	Compressive strength N/mm^2
Floor	Basement	-	Min 7100	3.48	3.24	-	High	High	37	600-800
	Floors	-	15216	273.765	43.36	-	High	High	510	800
Wall	Internal	-	8344	2.45	10.21	-	Medium	Medium	10	-
	External	Brick facade	7002	4.38	8.12	-	High	High	10	-
		Cement facade	10208	3.08	11.72	-	High	High	12	-
		Thermo wood facade	14952	1.81	18.55	-	Medium	Medium	43-223	-
		Stone facade	9902	4.22	7.51	-	High	High	37	-
Ceiling	Ceiling-Floor	Runner-foam	20152	216.875	14.85	-	High	High	509	800
		Cobiax	23342	119.755	12.97	-	High	High	1007	1600
	Roof	-	22164	118.65	37.72	-	High	High	1043	1600

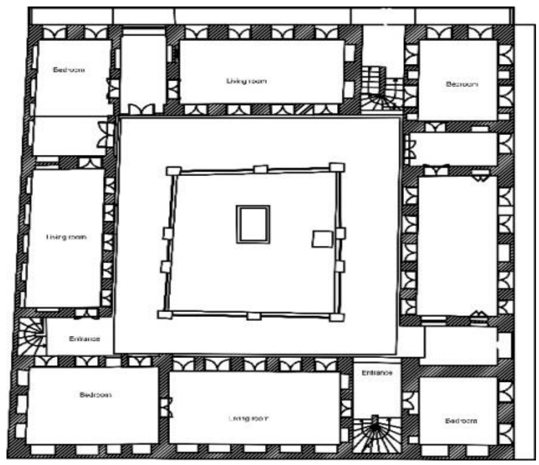
5.3. Comparison between Materials of Old and Contemporary Building

Upon scrutinizing the data presented in the aforementioned tables, discernible variations in heating and cooling loads emerge, constituting pivotal parameters in the climatic design for this region. Consequently, both building samples, representative of the historical and modern fabric of the city, incorporating the specified properties, underwent modeling using Ecotect software. The heating load (measured in kilowatt-hours) during cold months, the cooling load (also measured in kilowatt-hours) during warm months, and the average indoor temperature in both the old and new structures were then subjected to a comparative and analytical assessment leveraging Energy Plus. In order to execute this analysis, two residences were chosen—one from the historical fabric and the other from the contemporary fabric of the city—each characterized by the floor plans illustrated in Pictures 4 and 5.

Figure 6 depicts the heating load of buildings constructed with both old and new materials during the cold months in Boushehr. The heating load represents the amount of cold air that needs to be removed from the target environment (buildings) to maintain the desired ambient temperature and humidity. Notably, the figure illustrates that the heating load is considerably lower in the case of the older sample compared to the new one. Specifically, when employing old materials, the heating load approaches zero, suggesting minimal demand for heating. Conversely, in the instance of new materials, the building exhibits a cooling load during the cold season, peaking in the coldest month of the year, namely January, followed by February. The heating load for structures using new materials is minimal in January and February, registering values of 50 and 7 kilowatt-hours, respectively.



Picture 4. Old building sample



Picture 5. Contemporary building sample

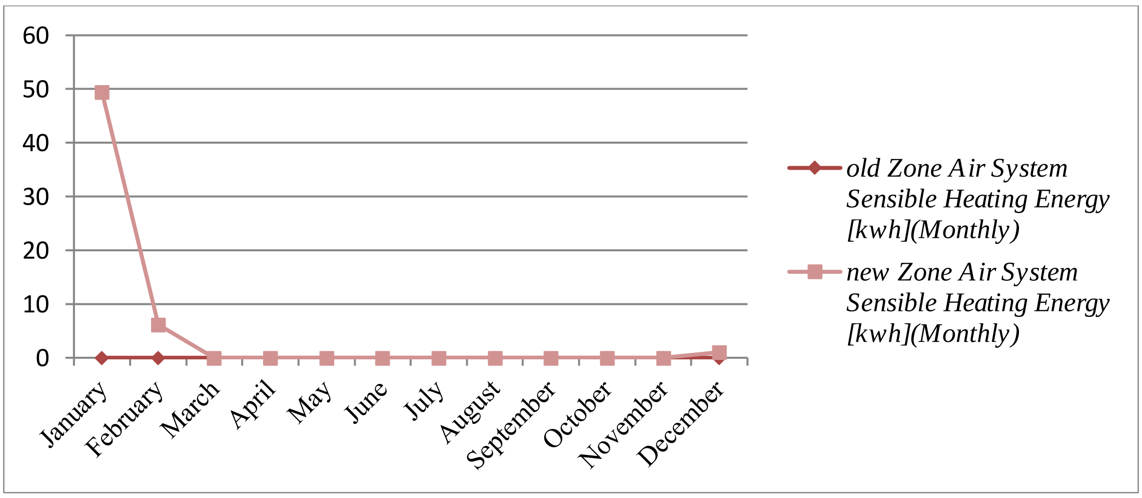


Fig 6. Thermal load comparison between old and temporary buildings materials

Figure 7 illustrates the cooling load of buildings constructed with both old and new materials during the hot months in Boushehr. The cooling load represents the quantity of hot air that needs to be expelled from the target environment (buildings) to maintain the desired ambient temperature and humidity. Notably, the figure indicates that the cooling load is notably lower in the case of the older sample compared to the new one. When utilizing old materials, the cooling load exhibits fewer fluctuations. The peak cooling load occurs in July, with a value of 1420 kilowatt-hours for structures employing old materials and 1630 kilowatt-hours for those using new materials. Subsequently, June and August follow in terms of cooling load, respectively.

Figure 8 presents the average monthly temperature of buildings constructed with old and new materials in Boushehr. The graph indicates that temperature fluctuations are reduced when using old materials. In essence, the average monthly temperature of the building with old materials tends to be closer to the comfort temperature, resulting in more favorable conditions. Conversely, the utilization of new materials introduces more pronounced temperature fluctuations. This is evident in the lower average monthly temperatures during the cold seasons and higher temperatures during the warm seasons, highlighting the more variable thermal conditions associated with structures employing modern materials.

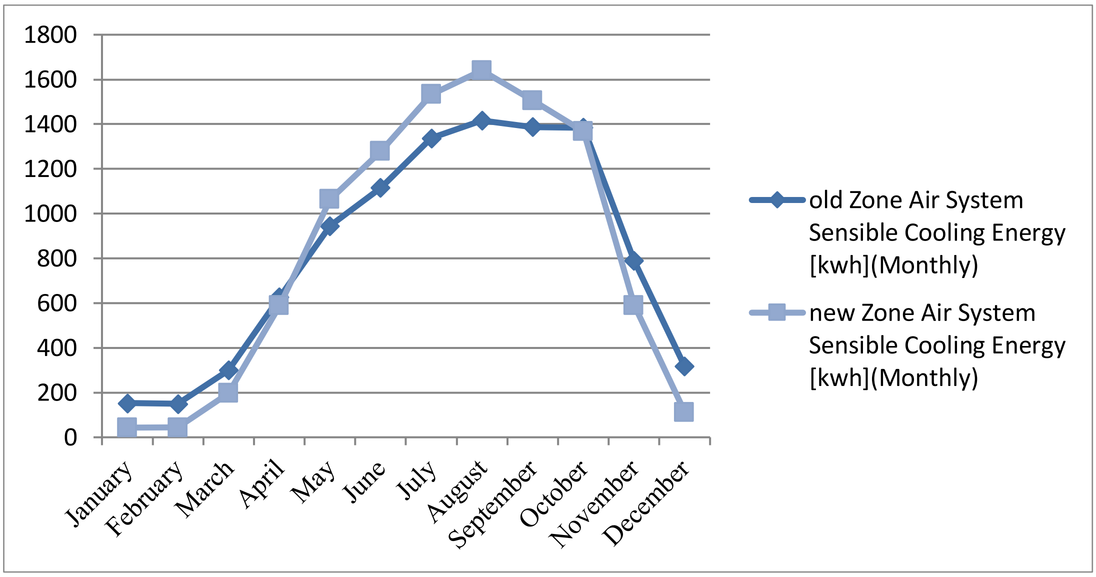


Fig 7. Cooling load comparison between old and temporary buildings materials

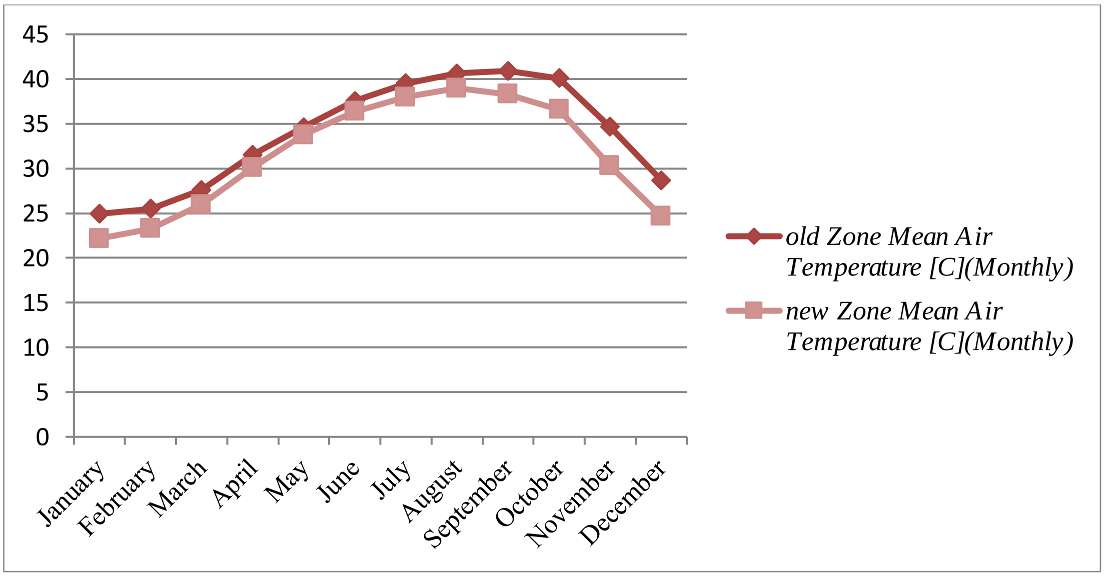


Fig 8. Average monthly temperature comparison between old and temporary buildings

6. CONCLUSION

The materials traditionally employed in the historical fabric of Boushehr are not only readily available but also adeptly cater to the city's climatic and aesthetic requirements. In contrast, modern materials are often utilized in new constructions to enhance attractiveness, introduce diversity, and create visual appeal. However, these contemporary materials are frequently employed without due consideration for their physical properties and construction principles, leading to a discordant and chaotic integration with the older fabric. Based on the discernible physical, chemical, and mechanical properties, it becomes apparent that the materials in the historical fabric outperform modern counterparts in terms of physical attributes. While advancements in technology have improved the chemical and mechanical properties of new materials, there remains a recognition that further modifications are necessary. Specifically, if the physical properties of modern materials, such as specific weight, conduction coefficient, and thermal resistance, can be adjusted to attain lower values, it is plausible that contemporary building materials could contribute to enhanced environmental sustainability. For a more comprehensive analysis of old and new materials within the warm and humid climate of Boushehr, two sample buildings were examined – one representative of the historical fabric and the other of the contemporary fabric of the city. The physical parameters, including being free on three sides, adjacency to the coastline, the number of floors, and building orientation, were intentionally kept consistent for both samples.

In the historical model, the walls exhibited a substantial thickness of 175 cm, a dimension significantly reduced to 75 cm in the contemporary counterpart. While the increased wall thickness in the historical model results in smaller architectural spaces on relatively confined plots of land and contributes to the overall weight of the structure, it serves as a notable advantage concerning the transfer of heat between the interior and exterior. The combination of considerable wall thickness and the porous nature of traditional materials contributes to excellent thermal insulation, facilitating a swift attainment of thermal comfort in both warmer and cooler seasons compared to the new building model. Despite the use of regionally sourced materials enhancing the environmental sustainability of the historical model, it falls short of embodying all sustainability principles. The considerable thickness of the older walls, while advantageous for heat transfer, is concurrently regarded as a drawback due to the resultant increase in the building's overall weight.

The average monthly temperature in the historical model is marginally higher than that in the contemporary model, attributed to the insulation properties of materials preventing heat dissipation from the building. However, given the superior performance of the historical model in both heating and cooling loads, material insulation emerges as a prioritized parameter. In the pursuit of identifying optimal parameters for environmentally sustainable building design in a warm and humid climate, and considering the manifold advantages of both historical and contemporary examples, a synthesis of their respective strengths presents an exemplary approach for constructing an ideal building suited to the region's climate. Contemporary builders and designers have access to a diverse array of materials, and based on the findings of this study, it is advisable to opt for porous materials with high thermal capacity, reduced thickness, and weight. Furthermore, materials employed in building facades are recommended to possess light colors to mitigate the impact of sunlight on the structure. In the past, the structural framework and openings in historical buildings facilitated natural ventilation, ensuring thermal comfort for inhabitants. Presently, this comfort can be achieved through the strategic use of appropriate materials coupled with the incorporation of cooling systems to expedite the attainment of comfortable temperatures. This holistic approach integrates traditional wisdom with contemporary advancements for enhanced environmental sustainability in building design within the specific climatic context of the region.

Conflict of interest: the authors declare that they have no conflict of interest.

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HOW TO CITE THIS ARTICLE

Nadoomi, R,. Sharghi, A,. Nakhaei,. Azadian, R. (2023).
Regional Materials and Environmental Sustainability in Hot and Humid Climates: A Study on Boushehr's Vernacular Houses. *Int. J. Architect. Eng. Urban Plan,* 33(4): 1-19, https://dx.doi.org/ijaup.713.

URL: http://ijaup.iust.ac.ir