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Toward Energy-Efficient Houses Considering Social Cultural Needs in Bahrain: A New Framework Approach

Ahmad Taki and Bilal Alsheglawi *

Leicester School of Architecture, De Montfort University, Leicester LE1 9BH, UK; ahtaki@dmu.ac.uk
* Correspondence: bilal.s.alsheglawi@dmu.ac.uk

Abstract: The residential buildings in Bahrain represent approximately 76% of the total buildings and account for 50% of the nation's overall energy consumption. Air conditioners account for over 70% of the electricity used in a typical Bahraini house. To date, no comprehensive study has been carried out on the energy efficiency of houses considering building envelopes, design, and social cultural needs in hot, humid regions with reference to Bahrain. This paper aims to develop and test a framework for energy-efficient houses that satisfies social cultural needs using mixed research methods. These research methods involved measurements of environmental parameters and observational surveys of 20 private houses. Additionally, a survey questionnaire was conducted with 111 householders to collect data on design preferences, thermal comfort, and energy consumption. Further, semi-structured interviews with 18 professionals were conducted and a range of simulations were carried out on a typical private house. Consequently, the framework was developed in three stages: data collection and analysis, specification of an energy-efficient building design satisfying social cultural needs, and producing a prototype model. Simulation results showed that the prototype house model can reduce energy consumption by 57% and operative temperature by 4 °C in comparison to the existing case study. The prototype model ensured privacy by adding two shaded corner courtyards and directing all the bedroom windows to face the courtyard. Feedback on the prototype was gathered to create a new and improved iteration of the future housing model.

Keywords: social cultural sustainability; energy efficiency; thermal comfort; framework; dynamic thermal simulation; case study; Bahrain

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1. Introduction

Globally, buildings that depend on non-renewable energy sources for heating, lighting, cooling, and refrigeration are considered the highest final end-use consumers [1]. Moreover, residential buildings are the primary energy users globally, representing three-quarters of the total energy consumption in buildings [2]. By 2050, energy demands are predicted to grow to almost the double the demands than that of 2010 [3]. Across the world, the growth in energy consumption has increased carbon dioxide emissions by more than 100% over the last four decades [4]. Additionally, in 2021, global energy demands rose and energy-related carbon dioxide emissions increased by 4.6% and 5%, respectively, the biggest rise since 2010 [2]. According to [5], if no serious action is taken to change current policies, greenhouse gas (GHG) emissions are predicted to grow by 58% and carbon emissions from energy related activities are predicted to rise by 78% from 2005 to 2050. Therefore, the United Nations established the Conference of Parties (COP), which represents global governments as signatories to the United Nations Framework Convention on Climate Change [6]. COP26 is the twenty-sixth climate change conference of parties aiming to limit global warming to 1.5 °C, cut the global emissions of carbon dioxide by half by the year 2030, and achieve net zero by 2050. These reaffirming aims finalize the outstanding elements of Paris Agreement COP21 in 2015 [6].

The energy consumption in the Gulf Cooperation Council has grown by 74% since 2000 and is predicted to further increase in the next few years [7,8]. Furthermore, the residential sector is the highest energy consumer among the countries in the Cooperation Council, most of which is accounted for by air conditioning [9]. In Bahrain, the predicted increase in CO_2 emissions is 7.7% per annum until the year 2050 [10]. Currently, housing in Bahrain faces two significant challenges: high energy consumption, and lack of social cultural features. In the case of the latter, this is specifically the lack of privacy required for household members [11,12]. According to [13], Bahrain has five electric stations that depend on natural gas and on oil, 83%:17%, to generate 4938 megawatt (MW) of electricity. Currently, there is no utilization of renewable energy sources in Bahrain [14]. Bahrain has an average solar radiation of 5.18 kWh/m^2/day with an average sunshine duration of 9.2 h [15]. Hence, there is good potential of using renewable energy sources, such as solar power [15]. Furthermore, according to a preliminary study of existing wind data, Bahrain has the potential to generate energy from both offshore and onshore winds [15]. Therefore, electricity and water authorities in Bahrain have a target of generating 5% of its total electricity production from renewable energy sources by 2030 [14]. In Bahrain, the residential sector is the leading energy consumer, representing 72% of the entire residential building stock and accounting for about 50% of the total power consumed in Bahrain [16,17]. Additionally, 70% of the energy consumption in a typical Bahraini house is accounted for by cooling due to the harsh climatic conditions. This requires the use of air conditioners on a 24-h basis during the hot seasons in order to achieve the desired thermal comfort [16]. Hence, it is of great interest to reduce energy consumption in the residential sector, thereby reducing CO_2 emissions. This can be achieved by considering energy efficiency measures in buildings as a first step toward achieving a sustainable society, environment, and economy amongst the Gulf Cooperation Council countries [5,7,18].

Many pieces of literature are focused on energy efficiency in buildings and its importance in achieving sustainability. Most of this literature emphasizes building energy efficiency through building envelopes only [16,19–21]. Another study [12] focused on the role of building design and construction materials in reducing energy demands in buildings located in hot, humid climates. A different study considered creating an analysing tool for bioclimatic design strategies in hot humid climates [22]. On the other hand, a study [23] focused on evaluating the impact of culture transformation on the sustainability of the urban environment in Bahrain. Moreover, [24] evaluated the social suitability of contemporary subsidised houses which are built for low-income families in Bahrain. A few studies focused on the evaluation of traditional buildings in terms of satisfying social cultural needs, and the social suitability of low-income houses in Bahrain [11,25].

There is a lack of comprehensive research in the literature that considers building performance simulation, including building envelopes, architectural design, and socio-cultural needs in hot, humid regions. Furthermore, in Bahrain there is no research that has considered or evaluated private contemporary houses' energy performances together with social cultural suitability. Therefore, this paper aims to fill this knowledge gap by producing a framework for energy-efficient houses that consider the social cultural needs. The specific objectives of this paper are therefore as follows:

- Evaluate the social cultural issues and energy performance of private houses in Bahrain.
- Develop a new framework for designing energy-efficient houses satisfying social cultural needs in the context of Bahrain.
- Produce a prototype house design to test the proposed framework.

2. Literature Review

The literature review of this study was based on selected key terms, including energy efficiency approaches, sustainable development, factors that affect energy consumption in buildings and building performance simulation to develop the proposed framework of this study. Nevertheless, literature on the context of this study was conducted to demonstrate social culture requirements for local housing and housing stock to select a representative case study. Hence, the literature on study context contributed to the development of the proposed framework.

Two major approaches have been developed to achieve energy-efficient buildings in different climatic zones around the planet [26]. The first approach focuses on using passive design techniques to lower the energy consumption in buildings, also known as the "easy efficiency strategy". This approach could reduce the energy consumption in buildings by approximately 40% compared to a similar, conventional building [26]. The second approach to achieve energy efficiency in a building is to adopt an advanced energy-efficient approach. This includes using on-site renewable energy technologies, such as solar panels, to generate the necessary power to operate the building applications [27].

2.1. Sustainable Development

The concept of sustainability became prevalent worldwide after the "Our Common Future" report was published in 1987 by the United Nations. The report defines sustainable development as development that "meets the needs of the present generation without compromising the ability of future generations to meet their own needs" [28]. Sustainable development requires a balance of several factors, including environmental resources protection, social progress, culture and economic growth, and current and future economic stability [29]. Sustainability aims to use the world's resources to achieve acceptable life standards in the long term and provide the same life standards to future generations, without harming humans or the environment [30]. To achieve the ultimate sustainability, social, economic, culture and environmental factors must be balanced in equal harmony [31].

Environmental sustainability maintains long-term environmental system components and functions for future generations. Hence, protecting the sources of raw materials by ensuring that waste arising from the use of natural materials does not exceed certain limits, which is essential to preventing the harm that may occur as a result [32]. Ensuring environmental sustainability requires an equilibrium between the activities associated with human development and sustaining a constant environment from which one can predictably and regularly gain resources [33]. The dimensions of environmental sustainability can be summarized as those of waste management, resource efficiency, site conservation, energy efficiency, indoor air quality, and water treatment [34].

A sustainable society should have the capability to preserve and build upon its resources. In addition, it should be resilient to any future issues that might occur [35]. Social sustainability can be summarized as constituting several main components: the right to have a house up to acceptable standards; an income that provides for the minimum life norms, such as food; the ability to access an appropriate education; the opportunity for self-development; and access to the networks that promote interaction and social cohesion [36]. These components are based on certain guiding principles, including equity, social inclusion and interaction, security, and adaptability [36]. The dimension of social sustainability is mainly concerned with the quality of human life, and hence the maintenance of cultural identity and the stability required to meet individuals' physical and psychological needs [37]. The empowerment of society members, safety, and equity are the main characteristics that socially sustainable communities aim to achieve for all their members [38].

A sustainable economy should aim towards environmental conservation and social prosperity to provide better lives for the current and future populace. Furthermore, a sustainable economy approach to the efficient use of resources, a reduction in the use of toxic materials and emissions of waste and pollution over the materials' life cycles, are required [39]. Thus, sustainable economy is related to the sustainable consumption of resources to provide basic needs and allow for better life quality. Furthermore, the sustainable economy is concerned with the growth, development, and productivity of societies, as well as the efficient use of materials and energy [40].

Cultural consideration is inseparable from sustainable development, as it is critical in identifying human needs, interests, and identity. Culture can affect the openness and cohesion of a society and cultural values form human life among the societies [18,31]. Hence, changes of human attitudes through culture can potentially shift societies toward achieving sustainable development. Cultural sustainability considers tangible and intangible cultural elements and has the potential to promote environmental, economic and social sustainability [31,41]. According to [42,43], it is important to consider the cultural aspect together with social, economic and environmental aspects to provide a comprehensive approach toward achieving sustainable development. Furthermore, cultural sustainability reflects the local culture and expertise in the built environment through building form, materials, and construction methods [18,31].

2.2. Factors Affecting the Energy Consumption in Buildings

2.2.1. Building Design

The consumption of large amounts of energy for cooling and/or heating is an indicator of poor building design [44]. Thermal comfort in buildings and a building's thermal performance are significantly affected by its design [45]. For instance, poor design can cause indoor temperatures to rise, which causes discomfort for occupants, resulting in excessive energy consumption due to the use of air-conditioning [46]. In developing countries, especially those characterized by hot, humid climates, one of the most notable reasons for a poorly designed building is lack of consideration of the microclimate of the selected region at the design stage, leading to unsuitable buildings for the climatic conditions in questions and, thus, the excessive consumption of energy [47]. Therefore, a building design that considers the microclimate conditions of a selected region and building envelopes in hot, humid climates can significantly reduce energy consumption. Hence, it will reduce greenhouse gas emissions and operational costs [48,49].

The passive design technique is the main route to achieving energy efficiency in buildings. Selecting a passive design technique that considers the local climatic conditions, building orientation on site, and building envelopes can enhance thermal comfort to the building occupants [50]. Additionally, the passive design technique can minimise the energy required for air conditioning [51]. Consequently, the following passive design techniques are used in this study to achieve energy efficiency in buildings.

2.2.2. Building Form

Building form can influence energy demand and consumption in buildings [52]. The heat gain and loss depend on the climatic requirements of the building region. A well-designed building with a simple shape and compact form that suits the microclimate of a selected region was more energy efficient when compared with a building that has irregular form [53]. In a hot climate, buildings should minimize heat gain to reduce the load on cooling. This can be achieved when the exposed surface area to volume ratio of the building is low [54]. Accordingly, [44] suggested the ratio of the exposed surface area to building volume ratio ranges between 1:1.7 and 1:3.

2.2.3. Building Orientation

The choice of the appropriate orientation is one of the critical decisions in ensuring an energy-efficient design [55]. The building orientation that suits hot, humid climates should aim to direct the short side of the buildings towards an east-west orientation [55]. Moreover, windows should not be placed on the east or west facades in order to enhance the natural ventilation and reduce the heat gain into the building [44]. According to a study by [56], the results of testing twelve bay orientation in hot, humid climates indicated that the bay that was oriented toward the north performed the best in terms of energy consumption as it received the least direct solar radiation, resulting in less heat being transferred into the building and thus a reduced cooling load. Nevertheless, the authors in [44] recommend residential buildings in hot, humid climate be oriented toward north for better natural ventilation and reduced heat gain. According to [57], no single orientation can suit all the buildings, and architects should test their buildings to find the most suitable orientation. Therefore, residential house orientation in hot, humid climates should opt for minimizing the heat gain by the building envelopes in order to reduce cooling loads.

2.2.4. Building Materials

For a hot and humid climate, it is not recommended to use high thermal mass construction materials in buildings due to their limited diurnal range. In contrast, low thermal mass materials are recommended because of their beneficial role in passive cooling [44]. Furthermore, the authors in [58] argue that if thermal mass materials are shaded and insulated correctly, they can suit hot humid climates and reduce night-time temperatures. The effectiveness of building materials in terms of energy performance is highly dependent on their thermophysical properties, such as conductivity, specific heat capacity, resistance, and surface convective coefficients [59]. Therefore, selecting appropriate building materials with specifications that suit the local climate of the selected building region will enhance the energy and thermal performance of the building [60]. Insulation materials can also reduce the cooling loads in buildings [19]. According to [19], placing the insulation materials on the outer side of the envelope results in better performance than placing them on the inside.

2.2.5. Building Envelopes

Building designers should avoid using thermal mass materials for wall construction in buildings that are in hot, humid climates because limited diurnal temperature range of thermal mass materials can negatively impact thermal comfort and energy consumption [58]. In [20] it is stated that external walls must be appropriately insulated to achieve energy-efficient buildings in hot, humid climates. Moreover, according to a study by [61–63], architects should implement lightweight wall construction with insulation materials, as this approach is highly effective at reducing the transmission of heat into buildings, thus reducing the energy required for cooling.

Roof construction design requires careful selection of component materials, especially in hot humid climates with intense solar radiation [19]. Different passive design techniques have been suggested for such climates to enhance building performance. One of the more widely used practices in roof design to reduce the heat gain in buildings and to achieve energy efficiency is to integrate insulation materials, such as polyethene [63]. Another technique used in roof construction to reduce the heat flux into a building is the addition of roof shading [64]. Additionally, the use of light colours should be considered on building roofs to reduce heat absorption, thus enhancing the thermal conditions in such buildings [65].

Unsuitable ground floor design for a building's climate region can cause thermal discomfort and increase the energy required for cooling [66]. Although different materials are used in ground floor construction, such as concrete, steel and timber, selecting ground floor materials and designs that suit the climatic region of the building is key to achieving energy efficiency in buildings [59]. In hot, humid climates, the use of thermally insulating materials is not recommended because they can prevent heat from being dissipated into the ground [67].

A window design that considers the type, size, location, and shading use can lead to energy efficiency in buildings [44]. One of the more significant aspects that needs to be considered when selecting appropriate window glazing is the solar heat gain coefficient (SHGC) [68]. The SHGC is the fraction of solar radiation that passes through the window via direct transition or via absorbing and releasing heat into the building [68]. Therefore, glass with a low solar heat gain coefficient ratio is excellent for reducing the cooling demands in hot regions. Furthermore, the number of layers of glazing and glazing type, which vary between single, double, and triple glazing, can affect the amount of light passing into buildings and the solar heat gain in the built environment, leading to lower energy requirements for cooling purposes [69].

The window-to-wall ratio (WWR) can control the amount of sunlight passing into a building [58]. Choosing the optimum window-to-wall ratio that suits the local climatic conditions is critical to energy efficient building [55]. Increasing the window-to-wall ratio in buildings can significantly enhance the natural ventilation and indoor thermal conditions. However, this can cause high solar heat gain, increasing the cooling energy consumption [70]. For hot, humid climates the recommended WWR is between 15% and 24% [71–73].

One of the most effective and essential passive design methods to reduce solar penetration into buildings is external window shading devices [74]. They can help to prevent buildings from overheating and thus minimise building cooling loads [55]. The authors in [75] concluded that a 30 cm-deep external shading device could offer 2.62–3.24% energy savings. Another study indicates that increasing the depth of the external shading device to 60 cm allowed for a 5.85–7.06% energy saving, whilst further increasing the depth to 90 cm allowed for an 8.27–10.13% energy saving [76]. Therefore, shading devices should be considered in climates characterised by intensive solar radiation to achieve energy-efficient buildings and should be designed appropriately [77].

2.2.6. Ventilation System

According to [78], the absence of natural ventilation in buildings can cause a building to overheat, making the building occupants highly reliant on mechanical ventilation to achieve the desired indoor temperature. Furthermore, mechanical ventilation that includes heating, ventilation, and air conditioning systems (HVACs) play a significant role in building energy consumption. For instance, mechanical ventilation systems can account for 50% of a building's energy consumption [79]. The building in the context of this study is indeed highly reliant on its mechanical cooling system, which accounts for 70% of the energy consumed [16]. Nevertheless, the high dependency on mechanical ventilation can be detrimental to the environment, contributing to serious environmental concerns, such as global warming [80]. Naturally, therefore, developing and enhancing the energy efficiency of mechanical ventilation systems and developing advanced building technologies that reduce buildings' energy consumption have been the topic of interest for the past few decades [81].

2.3. Building Performance Simulation

According to [82], the use of building performance software for modelling and evaluating a building is an effective method to analyse the building's thermal comfort, energy consumption and architectural design. Moreover, it is necessary to use building performance software to identify the most suitable improvements to the building design [80]. Hence, a building modelling and simulation tool is one of the research methods used in this paper. There are many different software/tools available to examine a building's performance. DesignBuilder is one building modelling software that integrates the EnergyPlus simulation engine to evaluate the whole building's performance [83]. DesignBuilder has a user-friendly interface with easy and accurate building geometrics to create a building model. Furthermore, it offers a wide range of templates that can be used in different space specifications, such as building envelope material templates, occupant activities templates, lighting controls and heating and cooling templates [83]. Further, DesignBuilder offers worldwide weather data and energy codes for any selected region [83].

One of the most used programs by engineers, architects, and researchers to simulate the whole building energy is EnergyPlus. It is an open-source and cross-platform software that can be integrated into DesignBuilder to simulate a Building model [84]. EnergyPlus is an accurate simulation tool used by the U.S. Department of energy for buildings heat, cooling, ventilation, and lighting evaluation [85]. DesignBuilder combining EnergyPlus outputs has passed three various tests, which are comparative, analytical and executable to comply with the industry simulation requirements [82]. Therefore, in this paper DesignBuilder combined with the EnergyPlus engine was used to model and simulate an existing building for performance analysis and test the framework prototype model.

3. The Case Study of Bahrain

3.1. The Climate

Bahrain is an Arabian country located on the southwestern coast of the Persian Gulf (also known as Arabian Gulf) (Figure 1). Bahrain's climate is classified as tropical and sub-tropical desert climate (BWh) as per Koppen–Geiger climate classification [86]. According to meteorological directorate in Bahrain and literature, Bahrain enjoys an arid climate, with mean annual rainfalls of 85.1 mm and high relative humidity [87–90]. The year can be split into two seasons: a very hot summer and a relatively mild winter. The average annual temperature is 25 °C [91]. However, the maximum monthly average temperature is 40 °C in July, and the minimum is 15 °C in January (Figure 2). The maximum recorded temperature is 47 °C in July. The winter period lasts from December to March, while the summer period lasts from June to September [90]. The two seasons are separated by transitional periods, from April to May before the summer starts and from October to November before the winter period. The average monthly relative humidity in Bahrain is 65%, the maximum recorded average relative humidity is 88% in January and minimum average is 39% in June, (Figure 3) [87]. The prevailing wind direction is north-eastern, with a maximum monthly average speed of 5.1 m/s (from January to March) and minimum monthly average speed of 4.1 m/s (from April to December) [90]. The daily average solar radiation in Bahrain is about 5.18 kWh/m^2 and the average daily sunshine is 9.2 [15]. Due to the harsh climate, Bahraini residents spend most of their time indoors. The hot, humid period extends to over six months. As a result, air conditioning is often required continuously throughout the day and night to achieve the desired thermal comfort. Hence, air conditioners account for over 70% of the electricity use in a typical Bahraini house [16].

3.2. Social Cultural Characteristics

In Bahraini society, gender segregation is practiced extensively both in homes and in public. In a typical Bahraini household, the females and males have separate bedrooms and bathrooms. Gender segregation can also be seen in public spaces in Bahrain, such as schools, at all educational levels [17]. The influence of Islamic culture is extended to the architecture typology and is apparent in various constructions and buildings. For instance, Islamic architecture can be viewed in religious buildings, such as mosques and places of worship, public buildings, such as libraries, and sustained neighbourhoods and houses [94]. Privacy–inspired by Arabic and Islamic traditions—is a very important aspect of the social cultural requirements. Privacy in Bahraini culture is formed on the concept of sanctity, or "Hurma" in the Arabic language [94]. The concept of sanctity is usually referred to with respect to religious places, such as the mosque. These places, considered sacred and pure, require guardianship. The Islamic religion also places a particular emphasis on the role of the house and its importance in providing privacy for both males and females [94]. Privacy is one of the main factors that drives the final design and space arrangement in Bahraini houses. Traditionally, privacy consists of four layers: privacy between neighbours, privacy between males and females, privacy between family members, and individual privacy [95]. These aspects of privacy can be achieved through the design aspects that control visual access by strangers and neighbours, noise, and olfactory transmission in and out of the house [91].

Hospitality is another aspect that characterises Bahraini society and is deeply rooted in the cultural identity of the country as a part of Arabic-Islamic traditions [94]. Inhospitable behaviour is not acceptable in Bahraini culture and is considered a source of shame [96]. Usually, rituals of hosting in Bahraini house require scenting the house with a traditional Bahraini fragrance known as "Oud" and providing the guest with traditional sweets and Arabic coffee. Moreover, if the guest arrives during lunch or dinner then it is obligatory to provide them a meal. Traditionally, male guests are hosted in separate reception rooms known as a "Majlis", while female guests are hosted in the family hall to ensure gender segregation inside the house [94].

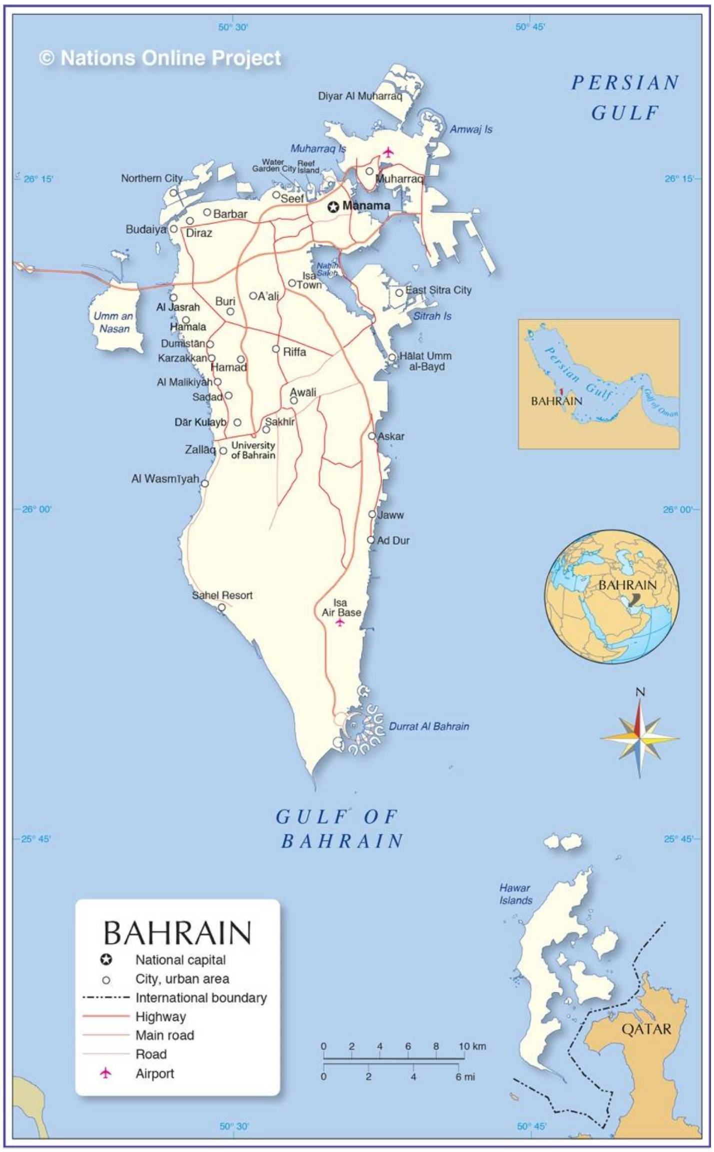


Figure 1. Bahrain location map [92].

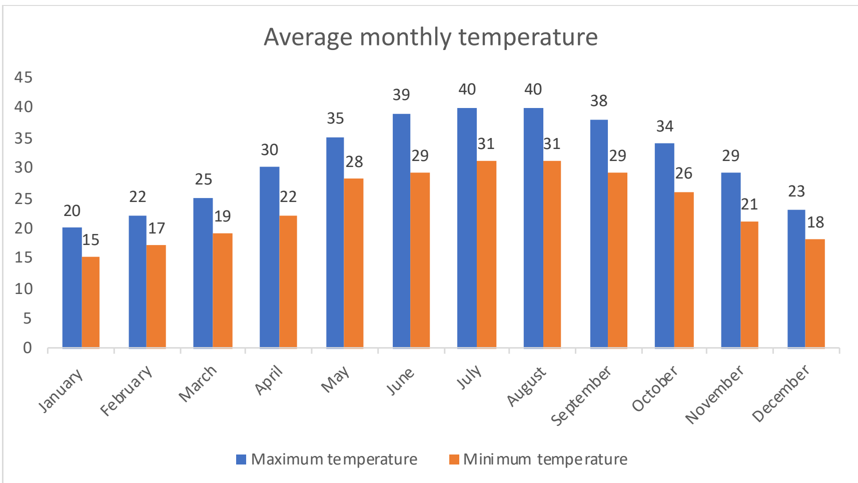


Figure 2. Average monthly temperature in Bahrain [93].

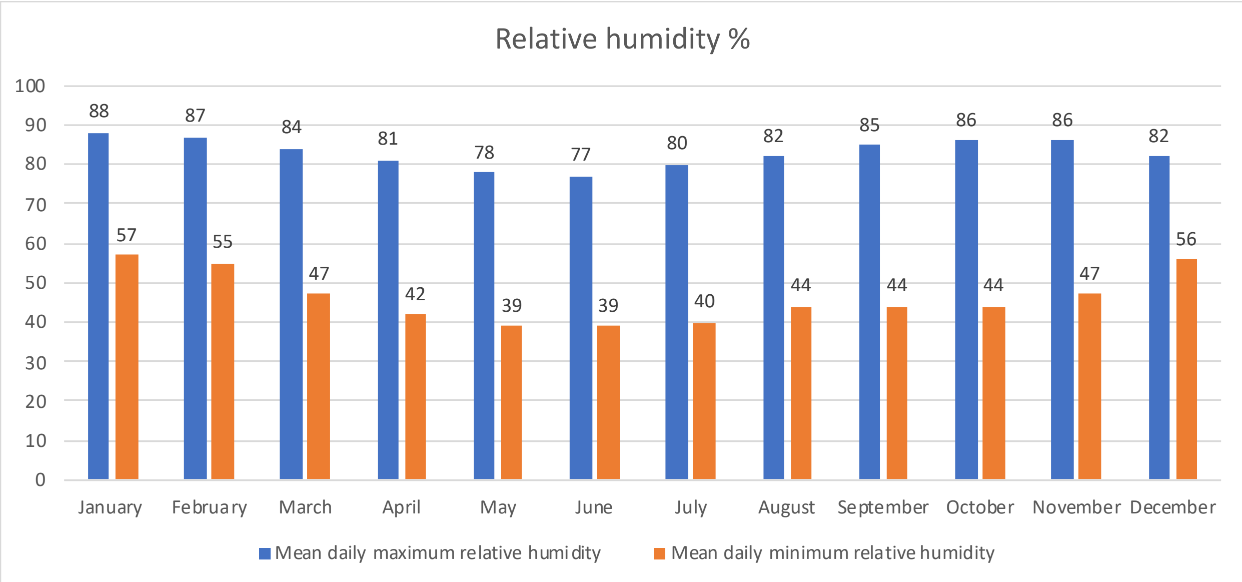


Figure 3. Relative Humidity in Bahrain [90].

3.3. Housing Stock

The residential buildings in Bahrain are mainly of four types: private houses, apartment buildings, conventional houses, and traditional houses [17]. Private houses are usually detached houses and double storey with a reception room, minimum of three bedrooms, inside and outside kitchen and living room, appropriate outdoor spaces and car parking spaces [97]. Conventional houses were built by the Ministry of Housing in Bahrain and distributed to limited income families. These are semi-detached with outdoor spaces and garages [98]. Apartment buildings are built by both private investors and the Ministry of Housing [97]. The remaining traditional houses are rare in the country and refurbished and employed as tourist destinations [11]. The remaining traditional houses are either empty or rented to labourers working in the country. According to [17], the total residential building stock in Bahrain is 192,125 units, divided into 35,123 apartment buildings, 137,284 private houses, 12,178 conventional buildings, and 7540 traditional buildings. Consequently, private houses represent 72% of the residential buildings (Figure 4). Therefore, private houses have been chosen as the focus of this study.

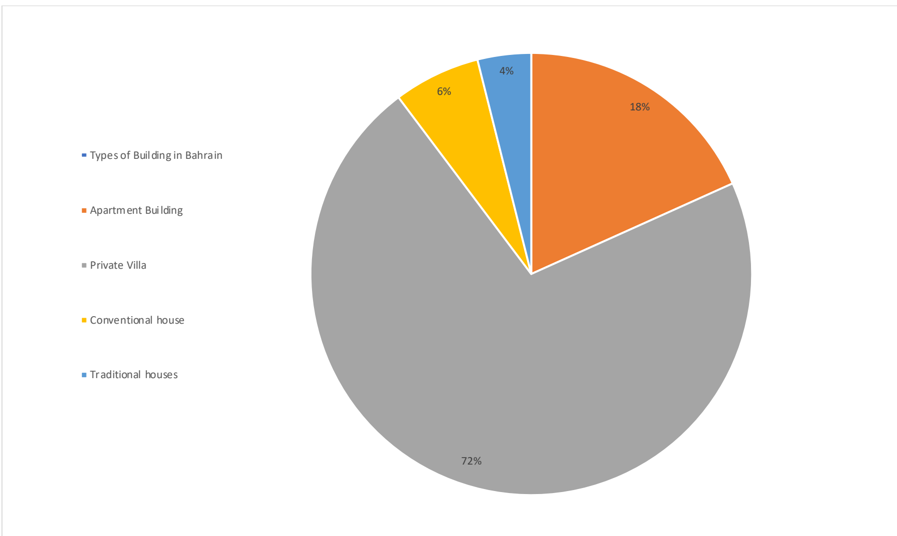


Figure 4. Types of residential buildings in Bahrain [17].

4. Methodology

This paper adopts both the concurrent and sequential mixed-methods approach. This includes observation survey, questionnaires and environmental measurements survey, semi-structured interviews, and dynamic thermal simulation of a case study. The methodological approach is appropriate to produce meaningful data to develop the proposed framework of this research.

4.1. Sampling Method of the Research

In this study, snowball sampling was used to create a representative sample for the observational measurement survey, semi-structured interviews, and questionnaire survey. This overcomes the discomfort felt by Bahrainis when allowing strangers into their homes. This cultural norm protects a family's privacy requirements and limits Bahrainis from allowing non-relatives from entering certain rooms in their houses. For the observational measurements and questionnaire survey, a visit was paid to a family friend located in Riffa, a major residential city in Bahrain [17], who was able to persuade others in the community to participate in the study. Additionally, a senior architect in the Ministry of Housing was interviewed, who, in turn, recommended other architects, civil engineers, and a project manager for further interviews.

4.2. Observation and Environmental Measurements Survey

In this study, 20 private residential houses were observed. Observational characteristics noted and photographed included the general design of a house, building typology, building materials, and construction techniques. This helped evaluate the impact of building characteristics on energy consumption, supporting the findings of the literature. Additionally, indoor and outdoor environmental conditions were measured, coupled with a subjective survey assessing occupants' thermal perception as they were sitting in the guest room. These included air temperatures, relative humidity, air speed and globe temperature. These measurements were essential to aiding the modelling and simulation of the existing case study and the development of the framework.

4.3. Semi-Structured Interviews

Face-to-face interviews were carried out with ten professional architects working in the private housing sector, four architects working for the Ministry of Housing, three civil engineers, and one project manager. The interview questions were designed to explore the interviewees' opinions on energy consumption in private houses, energy efficiency, social acceptability, and culture, and to seek their recommendations for future housing planning. The interviewees were asked to provide an opinion on several factors that may influence house design, such as the cost, the prevalent social cultural influences, and the influences of Western architecture on domestic architecture. Furthermore, the interviews examined the local population's acceptance of traditional architectural elements found in modern day buildings. The rich data produced from the semi-structured interviews helped understand the context of this study in more depth and helped compensate for the current lack of data on the characteristics of the private housing sector. In this study, content analysis was used to explore the textual information produced from the semi-structured interviews with Architects. Content analysis is a systematic and replicable method that uses coding to reduce long words into fewer content categories [99]. The process of analyzing this data included transcription, data labelling and referencing, coding, identification of critical points, and the development of theories and conclusions using NVivo computer software.

4.4. Questionnaire Survey

The questionnaire survey was designed for Bahraini families who live in private residential houses. A set of questions were distributed to 111 householders in a major residential city. In general, the questionnaire survey attempts to generate demographic information, user behavior toward energy consumption, the thermal perceptions of householders, and house details, design preferences and social acceptability of different designs. The data generated from the questionnaire survey helped to select a representative existing house to be the case study for this research. Data collected from the observational survey, semi-structured interviews, and questionnaires were used to model and simulate the case study, and in turn, to inform the development of a new framework. All questions were translated into Arabic to help facilitate interviewer-interviewee communication and produce meaningful data. The data from the questionnaires were entered into the Statistical Package for the Social Sciences (SPSS) computer software to analyse householders' answers. The measurements of the basic environmental parameters were made at the same time as the participants were completing the questionnaires. These measurements were entered into an Excel spreadsheet to assess the participants' perception of comfort.

4.5. Existing Case Study Simulation

The selection of the case study for this research was based on the fact that private houses represent the majority of residential private buildings in Bahrain. Only three householders gave consent to use their houses as a case study for simulation. One of these houses was selected for this research work as the most representative and suitable house with respect to design, age, size, and construction methods. The selection of the case study house was also influenced by the case study residents, through their willingness to collaborate and provide construction drawings, details of their daily activities, and their electricity bills. Hence, the chosen case study house represents the typical design used for private houses and is located in a significant residential city. The case study house was built in 2012, compliant with the recent design requirements in Bahrain. The size of the plot is 507 m^2 and consists of two floors. The selected house was investigated further using various methods, including the use of DesignBuilder. This simulation tool evaluates the house performance with respect to lighting, energy demands and thermal comfort and can be contextualized with respect to hourly weather data for the Bahrain region. Moreover, the occupancy profiles were gathered from the existing case study occupants. The infiltration rate was assumed to be 1.00 (ac/h) as per DesignBuilder construction templates. The case study house was first simulated using natural ventilation templates to identify the requirements under peak conditions. Thereafter, it was simulated using air conditioning to evaluate the energy demands. Additionally, different envelope designs were tested to determine the most suitable design for the reduction of energy consumption and provision of thermal comfort. The data produced from the simulations were fed into the design process to help inform the development of the framework for designing energy-efficient houses in hot, humid climates. The construction details of the selected case study are summarized in Table 1.

5. Findings and Discussion

5.1. Current Approaches to House Design

In the semi-structured interviews, all the interviewees agreed that privacy and gender segregation are the main factors to consider in the design process. The interviewees added further comments about house boasting, claiming that it has become a general phenomenon in the country and incorporating modern designs is an essential factor to consider in the design process. Therefore, modern architecture has become the current trend in Bahrain under the belief that newer is always better. In fact, the survey questionnaire with local people confirmed that 46% of local people preferred modern dwelling designs, 41% preferred a mix of modern and traditional designs, while only 7% preferred traditional Bahraini design and 6% preferred traditional Western design. Local people tend to create and duplicate these designs, neglecting any form of traditional elements. Hence, the most common features that can be seen in Bahraini houses are thick facades with high glazing ratio and the use of wood and stones as decoration, subject to the owner's budget. This has resulted in houses with elements that are not suitable for the harsh environment of Bahrain and its local community.

Table 1. Existing case study construction details.

Elements	Description	U-Value (W/m^2 K)
Ground floor	12 mm porcelain tiles 50 mm screed 150 mm precast concrete slab 50 mm polythene sheet Crusher fines	0.522
External walls	12 mm exterior plaster 200 mm hollow concrete block 12 mm inner plaster	1.901
Roof	4 mm bitumen waterproof layer 50 mm screed 50 mm polythene sheet 150 mm precast concrete slab 12 mm plaster	0.404
Windows frame	Powder-coated aluminium frame	5.881

5.2. House's Ability to Satisfy Social Cultural Requirements

It was noted through direct visual observation that houses often have large window openings. The standard window panel is 1000 mm in width, and 1400 mm in height as single panels, where each window usually contains two panels with 800 mm height from the ground; depending on the façade design, some have windows with openings that start from the ground level and extend to two meters. This does not help provide the required privacy level to residents (Figure 5).

Figure 5. Various window designs.

High external walls visually protect the ground openings in some of the houses (Figure 6). Hence, the ground floor openings are exposed to the exterior space (Figure 7).

Figure 6. Ground floor openings that are visually protected by external walls.

Figure 7. Openings on the ground floor are exposed to exteriors.

Additionally, the openings on the first floor are examples of being directly exposed to the external space, where ground and first-floor openings have no shading devices, as can be seen in Figures 4 and 5. Moreover, neighbours' windows overlook one another, violating the privacy of the house's residents. Consequently, the residents cannot open the windows or curtains for air or daylight as they can be seen by neighbours and passers-by on the street (Figure 8).

Figure 8. Windows overlook each other.

Many of the living rooms in the houses visited have two doors, one for the Majlis entrance, and an exit door. However, it was noted that the exit door in some houses faces the exterior door; ergo, if both doors were open simultaneously, one would have a direct view into the heart of the house from the street, severely disturbing the privacy of the residents (Figure 9).

The majority of the houses visited have large outdoor spaces (AlHoush) and can host different activities. According to the questionnaire survey, 45% of the participants use the outdoor space only during wintertime, and 10% of them use it during the whole year. Approximately 36% of the householders do not use the outdoor space at all at any time during the year, and only 18% of residents are satisfied with their outdoor privacy. The outdoor space is not used comfortably as neighbours' windows overlook it, and this can be found in the majority of the houses in Bahrain due to the difference in height between buildings and size/location of the windows (Figure 10). The observational survey also showed that houses have multiples windows resulting in a high glazing ratio (Figure 11). A high glazing ratio will not only increase the cooling demand due to heat gains, but they do not fulfil the privacy requirement. As such, residents keep both curtains and windows closed, relying on artificial lighting and air-conditioning devices during the daytime (Figure 11).

Figure 9. Inner door facing the exterior door.

Figure 10. Outdoor space.

Figure 11. Houses with multiple windows for one space.

5.3. The Use of Traditional Building Elements for Future House Designs

According to the survey questionnaire, 75% of the participants would prefer having a courtyard, but its design would need to be modernised. On the other hand, 14% of the participants would not want to have a courtyard, and 11% expressed indifference. However, according to the interviewees, designers are discouraged from using a central courtyard. People consider the courtyard to be a waste of valuable space due to the shortage and high prices of residential land. More concretely, the survey questionnaire shows that 75% of the participants would prefer to have a corner or side courtyard, whilst 25% would prefer not to have a courtyard at all. It is thus possible that a courtyard—a traditional architectural element—could be accepted by local people if its design was further developed and modernised to meet the current population's needs.

5.4. Thermal Comfort in the Houses

The preferred room setpoint temperatures were 22 °C, 20 °C, 18 °C and 16 °C, representing 15%, 45%, 30% and 10%, respectively. The participants stated they did not experience thermal discomfort as the air conditioning is switched on 24 h a day (or for as long as the space is occupied). Cars, workplaces, and markets are all air-conditioned. Furthermore, local people switch on the air-conditioning in the room (usually bedrooms and guestrooms) at least one hour before needed to ensure the room is at a suitable temperature.

- Thermal Sensation Scale

All the interviews with the householders were held in their guest rooms. The predictive mean vote (PMV) method was used to measure human thermal comfort. Hence the basic environmental parameters, such as dry, wet bulb temperatures, relative humidity (RH), air speed, and globe temperature, were measured. A Sling Hygrometer was used to measure both dry and wet bulb temperatures. Relative humidity was calculated by recording dry and wet bulb temperatures using the psychromteric chart. Air speeds were measured using an omni-directional anemometer. The globe temperatures were measured using a standard globe thermometer. The clothing level and metabolic rate were estimated to be 0.5 Clo and 1.0 Met. The mean radiant temperature (MRT) was calculated using the following equation [100]:

$$\text{MRT} = \text{Tg} + 2.44\sqrt{\text{V}}\ (\text{Tg-Ta})$$

where Tg is the globe temperature (°C), Ta is the dry-bulb temperature (°C), and V is the air speed (m/s). The operative temperature (Top) was then calculated based on Ta, MRT and V.

The actual mean vote (AMV) using the seven-point ASHRAE scale of thermal sensation was performed to examine participants' thermal sensation. It is represented by +3 as hot, −3 as cold and (0) as neutral feeling. The interview responses indicated that 35% of the participants felt warm, 25% felt neutral, 30% felt slightly warm, and 10% felt hot, while none of the householders felt slightly cool (Table 2).

Table 2. Sample of measurements and participants' perception.

Location	Ta °C	V m/s	RH %	Tg °C	Top °C	MRT °C	AMV	PMV	Personal Preferences
House 01	32.3	0.1	36	37.5	34.9	41.9	Hot	3.03	Cooler
House 02	25.6	0.05	37	26.0	25.3	26.5	Neutral	−0.35	No change
House 03	27.5	0.1	39	28.2	27.8	29.1	Sl. warm	0.53	Cooler
House 04	28.3	0.03	37	28.9	28.6	29	Sl. warm	0.90	No change
House 05	31.4	0.1	39	32.4	31.9	33.0	Warm	2.08	Cooler
House 06	28.7	0.2	38	28.3	28.5	28.6	Sl. Warm	0.49	No change
House 07	30.0	0.01	30	32.5	31.2	33.1	Warm	1.70	Cooler
House 08	30.1	0.02	40	31.9	31.0	32.6	Hot	1.83	Cooler
House 09	28.2	0.2	40	28.4	28.3	28.6	Sl. warm	0.44	No change
House 10	29.5	0.05	40	30.2	29.8	30.2	Warm	1.38	Cooler
House 11	30.8	0.05	40	30.9	30.8	31.4	Warm	1.75	Cooler
House 12	25.0	0.05	35	26.8	25.9	27.7	Neutral	−0.14	No change
House 13	26.3	0.05	35	28.5	27.4	29.8	Neutral	0.42	No change
House 14	28.6	0.05	48	30.0	29.3	31.0	Sl. warm	1.28	No change
House 15	29.7	0.05	49	31.4	30.5	32.8	Warm	1.74	Cooler
House 16	26.5	0.05	37	27.5	27.0	28.3	Neutral	0.29	No change
House 17	32.4	0.05	51	33.4	32.9	34.1	Hot	2.65	Cooler
House 18	30.6	0.1	39	30.8	30.7	32.5	Warm	1.62	Cooler
House 19	29.8	0.1	37	30.5	30.1	31.7	Warm	1.37	Cooler
House 20	26.0	0.1	39	27.3	26.6	28.3	Neutral	0.09	No change

- Comparing AMV to PMV

Table 2 shows that there is good agreement between AMV and PMV values. This indicates that the PMV model can be used to accurately predict thermal comfort in such environments.

During the interviews, the participants were asked about their thermal sensation and personal preferences. Approximately 65% of the interviewees preferred to be cooler, and 35% did not want change in their thermal environment.

5.5. Building Performance of the Case Study

The basic environmental parameters were measured during the visit to the case study building. These measurements are represented by house number 13 in Table 2.

An annual energy simulation of the existing case study was carried out to analyse the performance of the building fabric and to identify a set of improvement measures that could be proposed to potentially reduce energy consumption. Although the roof was assumed to be the primary source of heat transferer to the building, the insulation in the roof of the existing case study enhanced performance in this regard. However, the simulation results showed that the external walls are the major structural component involved in transferring heat to the building. The unsheltered exposed area and lack of insulation in the exterior walls made these the most significant mean of heat transfer compared to the other building envelopes. Further, the results showed that the case study's ground floor acts as a heat sink to transfer heat from the interior space to the earth.

5.5.1. Thermal Comfort Using Natural Ventilation

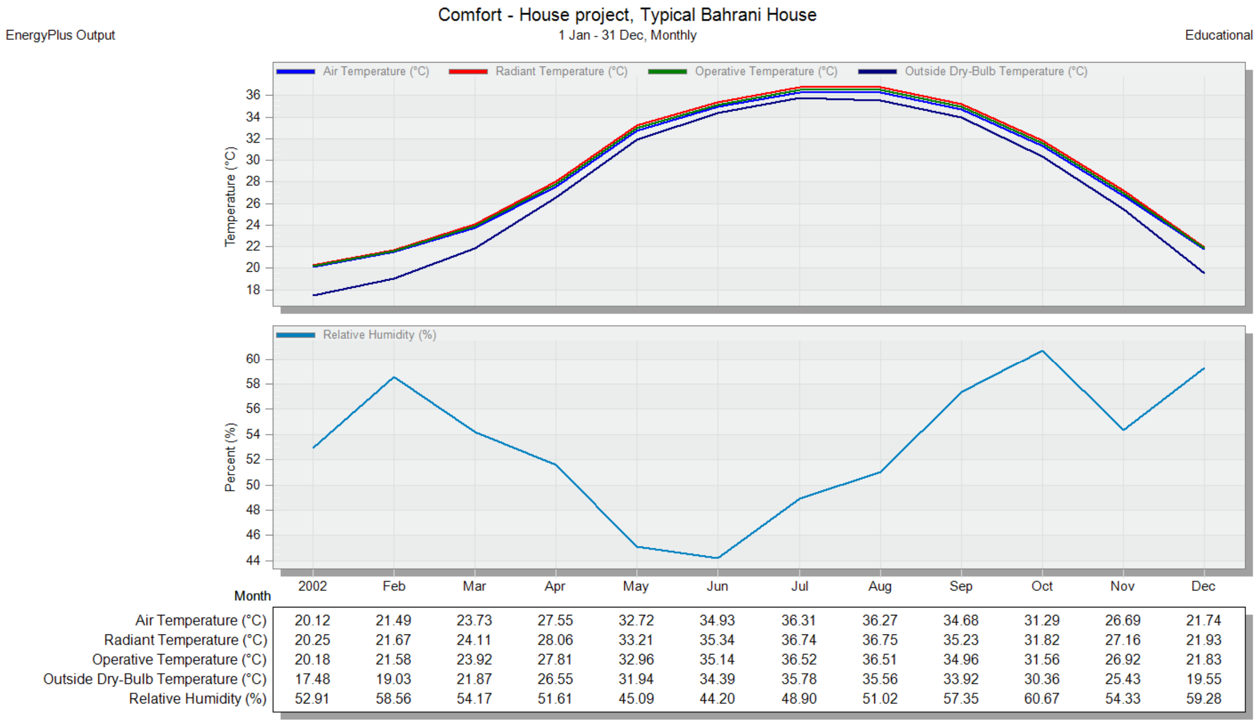
According to the survey questionnaire completed by Bahraini residents, the majority of people felt comfortable at a temperature range of 19 to 26 °C. According to the simulation results, people would feel comfortable inside their homes without using air conditioning during wintertime (November to March), where the operative temperature range was predicted to be in the range of 20 °C to 27 °C. However, from April to the end of October, the temperature would be 27.8 °C in April, peaking at 36.5 °C in August, then dropping to 31.5 °C in October. Figure 12 shows the monthly temperature results of the case study, which indicate the need for the use of air conditioning systems to achieve thermal comfort.

5.5.2. Energy Consumption

An annual energy simulation was carried out to analyse the energy performance of the case study. The results indicate that the existing case study consumes 89,072 kWh, which is 81.79% higher than the energy consumption using only natural ventilation. Furthermore, in order to validate the results of the energy simulation, a calibration process was carried out. This included a comparison between the simulation results for July and the actual July energy bill for the case study building; the energy simulation was found to be 1366 kWh higher than the actual case study bill for July, a difference of only 10%. This suggests that the simulation results are reasonably accurate in predicting energy consumption. The existing case study showed the annual energy consumption for interior lighting was 11,228 kWh, and 437 kWh for exterior lights. At the same time, room electricity and hot water account for 7622 kWh and 728 kWh, respectively. The demand for cooling accounts for 69,056 kWh, or 166 kWh/m^2 of floor area. The cooling load is the main contributor to energy consumption (Figure 13).

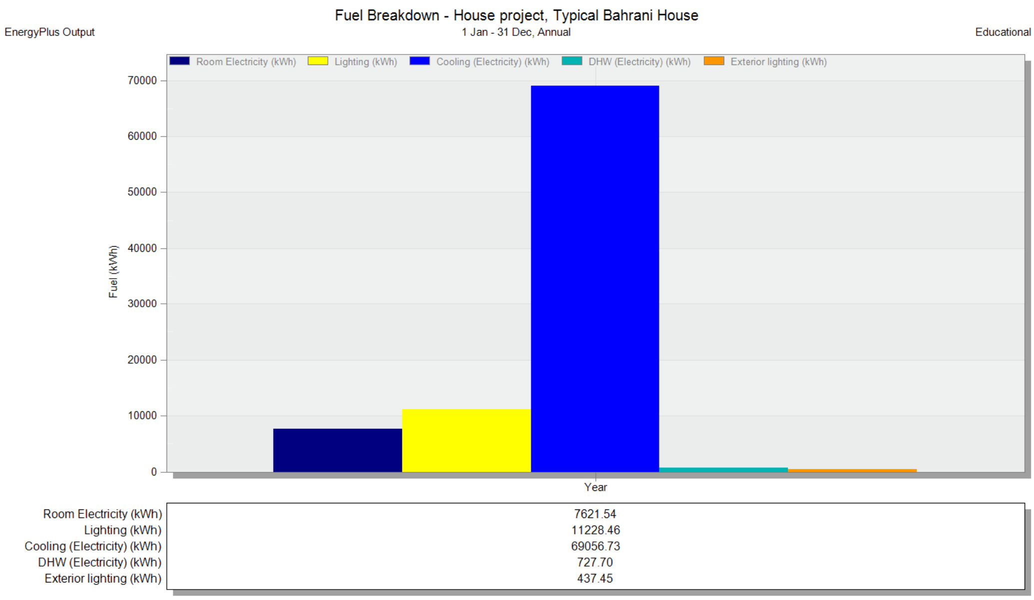
5.5.3. Improving Existing Case Study Envelopes

The improvements to the existing case study are applied to building envelopes, types of light, and building orientations. No change was applied to window size or building design. The results of the simulation where the existing case study parameters were upgraded show a significant difference in energy consumption, from 89,072 kWh to 45,918 kWh annually. The operative temperature of the hottest month dropped from 36.7 °C to 32.2 °C. The major energy savings were achieved by upgrading the external wall properties to a lightweight insulated wall that consists of 12 mm gypsum plaster, 50 mm polystyrene insulation, 100 mm concrete hollow block and 12 mm gypsum plaster, representing 28.35% of energy savings. The second highest energy saving potential can be realised by using low energy lighting, which allows for an 8.47% energy saving, followed by windows, ground floor construction materials, roof, and building orientation, offering 4.14%, 3.31%, 2.28%, and 2%, respectively. In terms of operative temperature, the ground floor showed a 2 °C reduction in operative temperature compared to the existing case study using natural ventilation. The remainder of the improved building parameters did not allow for any significant changes in operative temperature.



Month	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air Temperature (°C)	20.12	21.49	23.73	27.55	32.72	34.93	36.31	36.27	34.68	31.29	26.69	21.74
Radiant Temperature (°C)	20.25	21.67	24.11	28.06	33.21	35.34	36.74	36.75	35.23	31.82	27.16	21.93
Operative Temperature (°C)	20.18	21.58	23.92	27.81	32.96	35.14	36.52	36.51	34.96	31.56	26.92	21.83
Outside Dry-Bulb Temperature (°C)	17.48	19.03	21.87	26.55	31.94	34.39	35.78	35.56	33.92	30.36	25.43	19.55
Relative Humidity (%)	52.91	58.56	54.17	51.61	45.09	44.20	48.90	51.02	57.35	60.67	54.33	59.28

Figure 12. Monthly temperature for the existing case study using natural ventilation.



	Year
Room Electricity (kWh)	7621.54
Lighting (kWh)	11228.46
Cooling (Electricity) (kWh)	69056.73
DHW (Electricity) (kWh)	727.70
Exterior lighting (kWh)	437.45

Figure 13. Breakdown of energy consumption in the case study house using air conditioning.

6. The Framework

The adopted research methods for this study have led to the identification of the process that helped produce the framework for energy-efficient housing. This framework design was developed based on the research findings and data collected from the field of this study, which includes a questionnaire completed by 111 householders, and semi-structured interviews with 18 professionals in the residential sector. Therefore, the proposed framework considers the opinions of professionals who specialize in the residential sector, and design preferences of the building residences. The addition of a courtyard to the building was found to be an important design principle to provide privacy for the house occupants and to enhance the overall house performance in terms of energy consumption and thermal comfort. The development of the proposed framework was influenced by direct observation of 20 private houses and the findings from the literature review. Furthermore, the results generated from the simulation of the existing case study and testing different design applications had a considerable influence on the development of the framework for energy-efficient houses in this study context.

6.1. An Overview of the Framework Stages

The framework for designing energy-efficient residential houses can be divided into three stages: data collection and analysis (under the context of energy-efficient building designs satisfying social cultural standards), examination of the design, and the production of a prototype model. The stages in the proposed framework are sequential and expected to produce energy-efficient houses that suit hot, humid climatic regions. Architects can start the design process by collecting data about the region where the houses are intended to be built to develop a contextual understanding. This includes information about the social and cultural requirements, local environmental conditions, case studies of existing dwellings and building regulations. In case of changing the context of the study, it is recommended that the stages of the framework should be followed with relevant adjustments to suit the objectives. Stage two of the framework deals with specifications for energy-efficient buildings in terms of building design and building materials and construction. Finally, the third stage of the proposed framework illustrates the prototype of the design of the building that suits social culture requirement in the context of the study. Figure 14 demonstrates the stages of the proposed framework.

6.1.1. Data Collection Stage

Data collection is an essential step when producing an energy-efficient dwelling design that aims to satisfy social culture requirements, as this is the stage where the necessary data are gathered to understand the context of the study. This stage comprises four units. These units identify social cultural requirements, understanding the microclimate of the selected context, the case study, and the local building regulations. In the first unit, the architect should focus on understanding the social cultural requirements in the selected area, as this will allow them to create efficient house designs that are accepted by the local people of the specified context. Unit two is where the architect should collect information about the microclimate of the study context considering the information about the site and its surrounding environment. In addition to the literature about the climatic conditions of the selected context, a further physical measurement is recommended to determine the operative temperature and compare it with the existing data. Hence, this will confer a degree of reliability in identifying the suitable thermal conditions inside the buildings. Furthermore, a representative case study of the housing sector in the selected context should be considered. This will help architects to obtain data about the building performance that apply to typical local houses, especially in terms of thermal comfort and energy consumption. Finally, architects need to understand the local buildings regulations in the selected area to obtain a construction permit. After collection, the data should be evaluated to develop an understanding of the building region. Moreover, this will allow the architects to identify any missing data and fill in gaps before moving to the second stage.

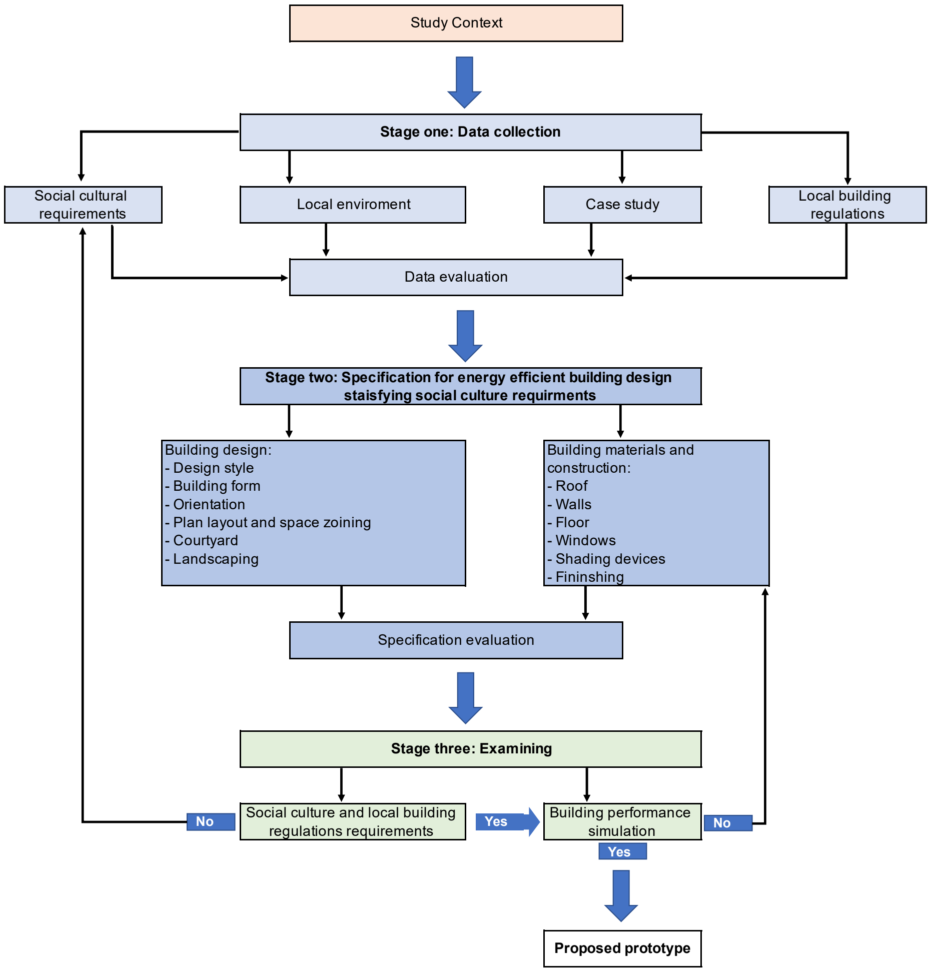


Figure 14. The proposed framework.

6.1.2. Specification of Energy-Efficient Building Design

According to the findings from interviews with professional architects who work on designing houses for Bahraini residents, people tend to preferer modern design styles over conventional ones, at the expense of cooling and privacy. However, architects argued that if traditional elements were modernized in the design, people would accept this practice; this was confirmed by the survey questionnaire. Consequently, this places a certain responsibility on architects and authorities to create awareness about the importance of reducing energy consumption and the potential comfort of high privacy. Furthermore, architects should implement traditional elements that enhance the privacy and thermal conditions inside the house, such as the courtyard. Simultaneously, houses should be designed to match current design trends. Furthermore, the professional architects also mentioned that Bahraini people often select the designs of their houses under the influence of western popularity on the internet and social media; in most cases, this leads to random designs within each neighbourhood. Hence, problems, such as windows overlooking each other, was a major issue that threatened the privacy of the house occupiers, and indeed the observations identified this issue. Thus, authorities should set guidelines and standards to accommodate both aesthetics and cultural requirements.

According to the results of simulating the orientation of the improved case study, the short side of the building should be oriented north-south to minimise exposure to the sun's radiation. This will reduce heat gains, resulting in less energy being consumed and improved thermal comfort. Such an orientation will also minimise the daylight passing into the building. Therefore, although there is no single orientation that suits all buildings, architects need to test their building design for the most suitable orientation.

The optimum plan layout and space zoning should consider occupants' preferences and thermal comfort, as well as what is good for the environment. Based on the primary research of this study, it was found that privacy and gender segregation are the main aspects that every Bahraini householder wants to ensure in their houses. However, people in Bahrain prefer modern designs with large openings, which has led to privacy issues and high energy consumption.

Based on the observational research, interviews, and questionnaire, the following guide points should be followed in order to design an energy-efficient dwelling that satisfies social cultural requirements:

1. A house plan shape with a maximum width-to-depth ratio of 1:1.7 will enhance the distribution of daylight and natural ventilation in the building.
2. An open plan design is suitable for maximising natural ventilation and daylight disruption. However, in the summertime, it can increase the cooling load. Since an open plan design is preferred by local people, the house architect should consider using adjustable space partitions.
3. In Bahrain, it is a cultural norm that when the male child marries, he lives with his parents, so the house plan should be flexible enough to accommodate possible future extensions.
4. The majority of residents live in and prefer two-story houses. Two-story houses are also ideal for privacy arrangements. For instance, the ground floor can host semi-public and semi-private spaces, whilst fully private spaces can be located on the first floor.
5. The house should consist of an internal kitchen for casual cooking and an external kitchen for heavy cooking to ensure odour privacy.
6. A standard house plan should consist of one reception room, one to two living rooms, two kitchens, storage, a minimum of three bedrooms, and enough toilets for the family members and a separate toilet for guests.
7. The toilet direction must not face Qibla for religious reasons. Qibla is the fixed direction of the Ka'bah, the sacred building in Makkah, Saudi Arabia, to which all Muslims face when performing their prayers.
8. The entrance to the house must not expose the living room to the exterior environment.

The reception room should have a separate exterior door, and it should be isolated from the private areas of the house to ensure the maintenance of privacy. The outdoor space should be visually sheltered to allow the female residents to use it freely. The directions that bedroom windows face should not be towards the main street.

- Courtyard

The use of a courtyard in a Bahraini house can provide various benefits to its residents, such as privacy and enhancing natural ventilation. The following points are a summary of the main design principles which were generated based on interviews, the survey questionnaire, and the literature review.

1. Avoid central courtyard designs as this is not preferred by Bahraini locals due to the limited plot area. Following the local buildings codes, two metres should be left empty between neighbouring buildings, which is not possible in the case of the central courtyard. Side or corner courtyards should be considered as an alternative to the central courtyard, which are preferred by Bahraini locals.
2. The courtyard should integrate manual or mechanical shading devices, such as fabric canopies, to minimise surface heat gain and reduce air temperature. Using shading devices can also reduce the dust caused by storms.
3. The courtyard should have a north-south orientation to maximise natural ventilation and reduce the exposure of internal surface.

- Landscaping

The use of vegetation in a Bahraini house is very rare; most householders replace any green space with ceramic or cast concrete flooring. This because of the harsh weather conditions (which makes it hard for vegetation to survive) and the required regular maintenance, added to which is the cost of buying soil. Therefore, there is high heat gain in the outdoor space, increasing the air temperature during the daytime and releasing stored heat during the night due to the excessive use of solid flooring. However, vegetation can provide good shading for buildings. Hence, it will reduce the house heat gain and ensure privacy for the occupants. Therefore, the house designer should consider the use of vegetation that has the ability to survive in such harsh climatic conditions and requires less care, such as palm trees. Moreover, the designer should consider minimising the use of ceramic and concrete floors and replace them with more green spaces. This will help to reduce heat gain and reflection, and thereby the air temperature.

- Roof

Typically, houses have flat roofs for various reasons. Primarily, the low rainfall, which does not require other specialized roof designs. The second reason is one of social cultural preferences, and roofs play a significant role in traditional houses; people sleep on the roofs at night, or host gatherings, weddings, and other social occasions. Although in modern life the house roof is no longer used for social occasions, the survey questionnaire revealed that a flat roof is still the most preferred type, and this is mostly because of the potential for future extension of the house floors they allow. The following points are the main considerations for a roof design that architects should follow:

1. An insulated light structure roof with a maximum U-value of 0.145 W/m^2 K and minimum R-value of 6.905 m^2 K/W is recommended. Improving the insulation to more than the recommended amount will not achieve any significant energy savings.
2. Avoid the use of white aggregate chipping as it rapidly deteriorates and turns into sand, which has high absorptivity and can act as heat storage.
3. Roof shading is highly recommended, as it can reduce the surface heat gain, and thus will reduce cooling load. Besides, it will provide privacy to the roof, and this can encourage the house residents to hold activities on the roof, in the same manner as in traditional Bahraini houses.
4. Using materials with light colours and reflective finishes is recommended as this can help reduce surface heat gain.
5. The roof design should consider space for renewable energy applications, such as solar panels.

- Walls

According to interviews with professional architects in Bahrain, locals do not use insulation materials in the external walls to reduce the cost of the house construction. Moreover, different types of walls used in building construction were tested, and the results suggest possible energy savings of up to 18%. The suggestion was to use cavity walls with a maximum U-value of 0.518 W/m^2 K. However, the interviews with architects stated that people would not choose such an option as they would then have to compromise on room size. Moreover, the cost of the cavity wall construction can be a deterrent. Therefore, the following suggestions are for residential house external walls, which were formed based on the literature review, interviews, and simulations:

1. An insulated lightweight wall structure with a short diurnal temperature range is the most suitable option for hot, humid climates.
2. A maximum U-value of 0.306 W/m^2 K and minimum R-value of 3.264 m^2 K/W is recommended for external walls in hot, humid climates.
3. Improving external wall insulation with a maximum U-value of 0.173 W/m^2 K and minimum R-value of 5.764 m^2 K/W has a significant impact on energy savings.
4. Using light, highly reflective colours on external walls can help to reduce any solar gains.

5. For internal walls, the recommendation is to use uninsulated walls, as they are not exposed to solar radiation. However, for the guest room walls, the recommendation is to use insulation as this will ensure sound privacy.

- Floor

Although various floor designs were tested in this study, the following are the main points recommended for floor designs in hot, humid climates:

1. The floor should act as a heat sink and transfer heat from the space to the ground; in order to achieve this, it is recommended to use floor materials that have high conductivities, such as metal. The higher the conductivity, the better the performance.
2. Insulation is not recommended for residential ground floors.

- Windows

1. The window-to-wall ratio should not exceed 15%.
2. The windows should have appropriate and effective shading devices.
3. Windows could be designed to provide natural daylight whilst still maintaining visual privacy.
4. Mashrabiya (a type of projecting oriel window enclosed with wood decoration) could be considered in the house design due to its ability to provide privacy, natural ventilation, and reduce solar reflections.
5. It is recommended to use double glazing with a maximum U-value of 2.347 W/m^2 K to help improve the thermal comfort and enhance sound privacy for the householders.

- Shading

It has been noted through direct observation that nearly all houses lack shading devices. The householders depend mainly on internal curtains to control solar radiation. The overhang and louvre shading devices starting at 50 cm to 100 cm in depth were adopted to determine the optimum choice of shading devices that reduce cooling loads and enhance the thermal conditions. The following are the main strategies that architects should follow when choosing shading devices for residential buildings:

1. 50 cm depth as a minimum is recommended for overhang and louvre shading devices. Increasing the depth to 1 m will not allow for any significant energy savings.
2. Shading side fins with overhang or louvre shading is recommended for maximum energy savings.
3. For increased privacy, louvre shading is recommended. However, it should include a mechanical or manual strip controller.
4. On the ground floor, if the exterior fence walls are higher than the window level and the distance between them is at most 1 to 2 m, there is no need for shading devices.
5. For shading device materials, low absorbance and high reflectance features are recommended to reduce solar gains.

6.2. Prototype Simulation

Buildings should meet the social and cultural requirements and local building codes. Furthermore, the building should provide an acceptable level of privacy to the householders, ensuring appropriate space zoning and plan layout. When the building passes the first stage, testing building performance can then be carried out. Such an evaluation can be performed for energy consumption and interior operative temperature using simulation software, such as DesignBuilder. The simulation outputs are used to inform building design and recommendations.

6.2.1. Design and Layout

This research has revealed the importance of integrating courtyards into houses to provide privacy, thermal comfort, and social cohesion. Therefore, the prototype model is based on integrating a corner courtyard into the existing case study. The spatial organisation of rooms varies according to the privacy level and functionality. The prototype highlights the importance of family privacy, and it is divided into different zones for both males and females. The bedroom windows were redirected toward the courtyards in order to reduce the solar gain and to provide privacy to the bedroom occupants. Further, the addition of two courtyards will reduce the exposed area of the prototype to sunlight, reducing solar gain through the external walls. The energy consumption for air conditioning is, therefore, reduced. However, the front courtyard is semiprivate, its intended use for family gatherings with friends and male guests. The back courtyard is private and to be used by family members and female guests only. The two courtyards will satisfy the social cultural requirement of gender segregation in Bahrain.

Although bedrooms should be located on the first floor for privacy reasons, the prototype layout kept one bedroom on the ground floor, as per the case study, for several reasons. First, having a bedroom on the ground floor will allow more flexibility for the house regarding potential future expansion so that the ground floor can act as an apartment on its own. Secondly, considering the case study residents' preferences, elderly parents prefer not to use the stairs to go to their bedroom. Therefore, the ground floor consists of the guest room, living room, external and internal kitchen, and bedroom. The second floor consists of four bedrooms, and the third floor consists of space that can be used as an additional storage or a maid room, depending on the residents' preferences (Figure 15).

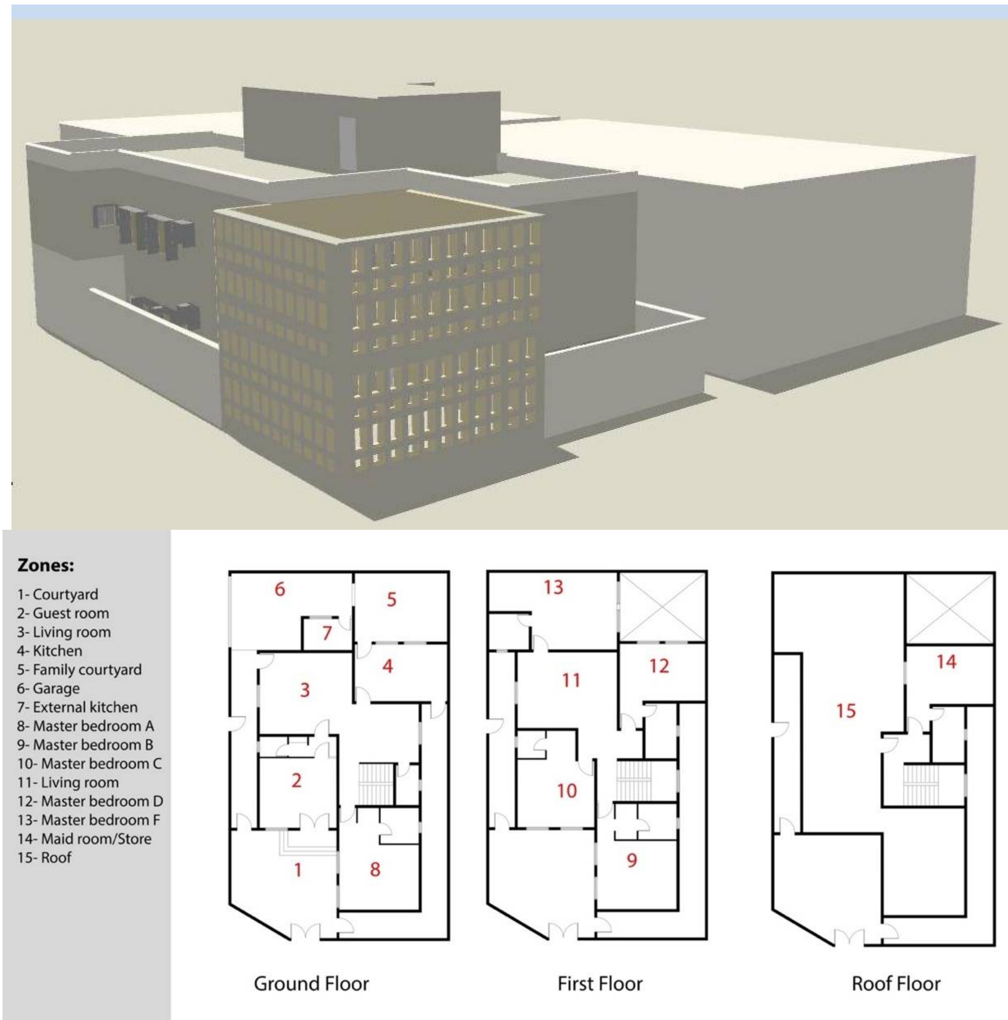


Figure 15. The prototype 3D model space distribution.

The construction materials in the prototype are guided by the recommendations of the proposed framework. The specification of the materials used in this prototype are summarised in Table 3.

Table 3. Prototype model construction details.

Elements	Description	U-Value (W/m^2 K)
Ground floor	20 mm porcelain tiles 80 mm floor screed 20 mm stainless steel floor sheet 200 mm compacted earth filing	1.531
External walls	16 mm lightweight plaster 50 mm polystyrene 100 mm concrete hollow black 16 mm lightweight plaster	0.496
Roof	30 mm gravel 4 mm bitumen layer 80 mm roof screed 100 mm polythene layer 200 mm precast concrete slab	0.145
Window frame	Wooden frame	3.633

6.2.2. Prototype Simulation Comparison with Existing Case Study

- Operative temperature using natural ventilation only

The existing case study and the prototype model were simulated using only natural ventilation (no heating/cooling template) to evaluate the performance of each model in terms of the annual operative temperature. The results of this simulation showed that the existing case study gave the highest operative temperature. For example, the August average temperature was 36.5 °C. On the other hand, the prototype model showed 4 °C lower operative temperatures, as can be seen in Figure 16.

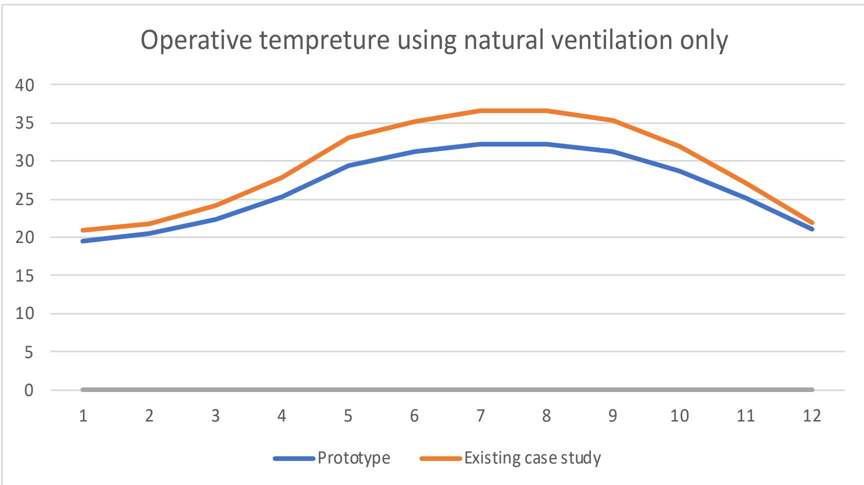


Figure 16. Monthly operative temperatures using natural ventilation for the existing case study and the prototype model.

- Annual Energy Consumption

An annual energy consumption comparison was carried out to determine which model performed the best in terms of energy demands, using a mechanical cooling system. For this simulation, the spilt no fresh air template was used. The existing case study resulted in the highest energy demands with total annual consumption of 89,072 kWh. The prototype model showed energy consumption of 38,459 kWh, a reduction of 57% (Figure 17).

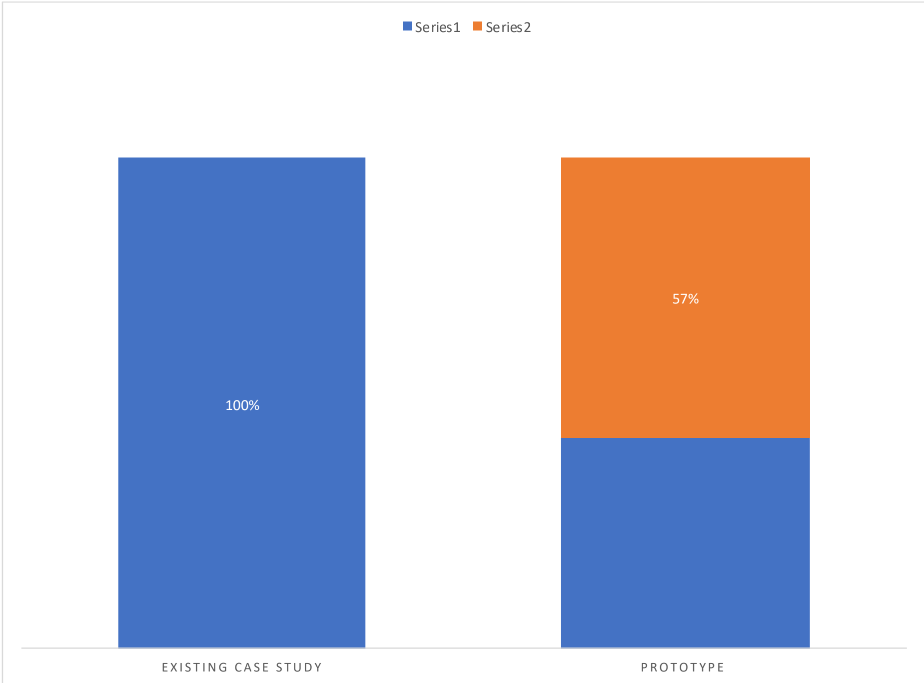


Figure 17. Energy consumption comparison between the existing case study and prototype model. Series 1: energy consumption, Series 2: energy savings.

6.3. Feedback on the Prototype

The employment of a courtyard would serve the purpose of gender segregation and the required privacy level. This would allow family members, in particular female members, to use the outdoor space more often. Changing the direction of any windows to face the courtyard rather than the main street would give more freedom to open them. The participants were asked to give their opinions on the prototype model design, and its suitability for the social cultural requirements for Bahraini families. Additionally, the architects were asked to give feedback on the courtyard and its suitability for its intended purpose. Finally, the participants were given the opportunity to suggest further improvements to the design of the prototype model. The five architects selected for feedback also participated in the semi-structured interviews. These were referred to as P1, P2, P3, P4, and P5. All the participants agreed that the prototype model would satisfy the needs of Bahraini householders in term of level of privacy, space division, having an external kitchen, a maid room, dedicated guest rooms, and appropriate room sizes. They all agreed that the employment of courtyard in the house design would enhance the level of privacy and would encourage the family members to engage in more outdoor activities. Moreover, they all suggested covering the courtyard would help protect the house against seasonal dusty sand winds. However, P2 stated there are too many divided spaces, requiring the use of many doors, which can increase the building cost. Additionally, P5 stated there should be more emphasis on the living room entrance; it should be more majestic representing the main entrance to the house. P4 also suggested changing the indoor kitchen's location, as it faces the courtyard directly, and this can allow dust to pass through the kitchen's ventilation vents. P2 suggested having a sloping edge parapet wall rather than a corner wall (see Figure 15) as this will enhance the view of any drivers passing through the street. Regarding the external section of the house, P5 suggested the courtyard vents should start from at least 1.8m above the ground level to ensure more privacy for the householder during the use of the courtyard. P1 suggested having vegetation in the courtyard to increase outdoor activities and reduce dust and that the house's sidewalk should be covered with a screen that allows light—but not direct solar radiation—to pass as this would reduce the heat gain through the external walls. P2 suggested having a simple garden design on the house roof to increase outdoor activities and reduce heat gain through the house roof. Finally, P3 expressed concerns regarding the cosmetic/aesthetic view of the house caused by the shading devices as each window would be shaded separately rather than sharing a shade.

7. Output and Impacts

The research process contributed to the knowledge and understanding of energy-efficient buildings in hot, humid climates in the context of Bahrain. The key contributions to knowledge can be outlined as follows:

- The development of a framework for designing energy-efficient houses that satisfy social cultural needs in hot, humid climates and tested by producing a prototype. This produces knowledge and practical design guidance about spatial organisation of rooms for family privacy, engagement with the outdoor space, and enhancing human comfort, whilst minimising energy consumption. Such guidelines can be adopted in other regions with similar climates and cultural values to help improve the relationship between human interaction and engagement with the surrounding built environment, creating better places for occupants.
- Courtyards can provide an excellent level of family privacy, and also help control indoor temperature and enhance social cohesion.
- The output of this research helps establish a robust methodology which can then be adopted in other regions with different climate characteristics and variations that would affect the use of indoor spaces, enhancing occupants' satisfaction.
- The proposed prototype model indicates a reduction of 57% in energy consumption. This energy saving would help improve and protect the environment, producing savings for occupants through reduced energy bills, and enhancing their satisfaction.

8. Conclusions and Recommendations

The cooling demands in buildings consumes 70% of the electricity used in a typical Bahraini house. The carbon dioxide emissions are predicted to increase yearly if policy makers do not implement energy efficiency improvements to the current building design approach. The findings from the data analysis confirm that current houses consume a large amount of energy because they are not suitable for Bahrain's climate and do not satisfy a major aspect of social cultural requirements, such as visual privacy between householders and neighbours. The key findings from simulating the current case study suggest that the external walls are the principal source of heat transfer, causing thermal discomfort. Improving the thermal performance of the external walls could thus lead to significant energy savings. Based on the data collected, the framework was produced in three stages. The first stage was data collection and analysis from the study context. The second stage was specification of energy-efficient building design that satisfies social culture needs. The third stage was an examination of the design and producing a prototype model. The prototype was produced based on the framework and was tested using a range of simulations. The prototype model ensured privacy by adding two shaded corner courtyards and directing all the bedroom windows to face the courtyard. Further, the simulation results indicate that this prototype can reduce energy consumption by 57% and operative temperature by 4 °C in comparison to the existing case study. Furthermore, the feedback on the proposed prototype 3D model and space distribution was also collected from the architects and existing case study owner who participated in the work field, confirming its ability to provide privacy and to satisfy the social cultural needs of house users. The spatial organisation of rooms varies according to the privacy level and functionality, highlighting the importance of family privacy. Privacy is among the aspects sacrificed in modern houses, where the outdoor space (AlHoush) is hardly used for any purpose of social life. The prototype creates a new and improved iteration model for the future of sustainable housing in Bahrain.

The potential areas of future research that may well be worthy of investigation could be summarised as follows:

- A detailed cost analysis of the various improvement measures proposed in the current energy-efficient housing design.
- The validation of this framework could be achieved by building an actual prototype model for future research. This would help quantify the research impacts on the local community's wellbeing.
- Investigate the existing passive cooling techniques and local construction materials found in traditional houses that could possibly be adopted in modern houses.

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