J. Umm Al-Qura Univ. Eng.Archit.
https://doi.org/10.1007/s43995-024-00049-1

ORIGINAL ARTICLE

Optimal urban sustainable design for residential village in Al-Baha region: application five roles strategies

Naief A. Aldossary[1]

Received: 4 December 2023 / Accepted: 17 January 2024

Abstract
This paper evaluates and discusses the proposed design for a low carbon environmental village in Al-Baha region. It considers its viability in view of local renewable energy sources, climatic conditions and local vernacular architectural identity. Five areas were targeted when designing the village: (a) low carbon architectural design strategies; (b) on-site renewable energy strategies; (c) selection of local construction materials; (d) exploitation of rain water harvesting and greywater recycling; and (e) waste disposal recycling and management. The used approach is to design a sustainable village with its facilities in prospective of environmental requirements social needs. The design follow application five roles' strategies from the literature and depending on local site challenges, available of natural in a location of Al-Baha gate from the airport. The site selected is located along the main highway that connects Al-Baha city to its nearest airport. The chosen area is 4,945,000 m^2 and has a flat topography with mountains located relatively close by. The findings present in the study plans for comprehensive sustainable low carbon energy village, which meet the climatic requirements and exploiting natural resources operated by natural renewable energy. This village is designed for typical Saudi families, and will be built from local construction materials. The design includes more than 6150 residential units powered by photovoltaic (PV) panels, and local services using wind energy. The energy requirements for the whole village were calculated based on macro and micro energy generation. Local regulatory standards and sustainability criteria have also been met for the proposed village. Five experts also evaluated the five-purpose design proposition. The impact of designing sustainable villages will lead in protection of environment improved the life and health quality as well as economic benefits. The benefits of addressing five aims are highlighted and the study concluded with some recommendations.

Keywords Sustainable village · Low energy design · Urban sustainable design · Vernacular architecture

1 Introduction

Recent decades have witnessed growing public concern surrounding sustainable development requirements worldwide. Much debate has focused on resolving the social and environmental problems associated with rapid urbanization. In particular, the development of sustainable neighborhoods has increasingly attracted interest [1]. Taking steps to protect the environment by managing CO_2 emissions is a global trend in multiple domains, including transportation and mobility and the built environment [2]. Residential neighbourhoods and districts in the kingdom of Saudi Arabia suffer from a lack of an integrated approach to environmental, economic values, which leads to issues such as; a low standard of life quality, inadequate environmental protection and ineffective transportation [3]. At the nearby level endures districts in Middle easterner and other Arabian countries numerous of the natural issues, on numerous levels begin to deplete energy generation from fossil and water demand and expanding squander extent of vitality without the good thing about them which highlights negative slant towards the exhaustion of natural assets [4].

Sustainable low energy villages and neighborhoods that exploit renewable resources are expected to play a significant role in reducing energy demand henceforth, by improving sustainability standards in areas with high levels of access to renewable energy resources, such as solar and wind energy [5]. The Al-Baha region is characterized by a combination of coastal, mountainous and flat topography, with good access

✉ Naief A. Aldossary
dr_naief@bu.edu.sa

1 Department of Architecture, Faculty of Engineering, Al-Baha University, 1988 Al-Baha, Saudi Arabia

to renewable resources. The region has many villages distributed across it, due to its social composition.

It is essential to ensure any new construction meets sustainability criteria, with designers expected to focus on strategies to minimize energy consumption and demand. This can achieved by starting at the level of local residential units, moving up to the level of neighborhoods and/or villages. Hence, any new village should be developed reflecting concerns over both the health of its inhabitants and the natural environment [6]. Designing a sustainable village for the future requires multiple facets be considered to ensure a cutting-edge and sustainable design [7]. Therefore designers need to emphasize a clean and healthy environment, prioritizing future sustainability. Application of macro and micro energy generation in remote villages is important, as many remote villages currently have limited access to electricity. To fulfil environmental objectives, new villages should be designed with essential services, powered by renewable energy, ideally generated locally. Using local renewable resources and local construction materials and educating people about sustainability and environmental responsibility to support a healthy life style is crucial [8]. Designing sustainable villages and neighborhoods by implementing sustainability criteria is the aim of this research. It seeks to provide an ideal model, that can be used to demonstrate how a sustainable village can be managed socially and environmentally. The village design will focus on residential units that fulfil environmental architectural requirements, implement renewable energy sources and provide vital infrastructure and services as well as open spaces. The sustainable village will reduce biologically and socially toxic challenges, enrich and promote prosocial behavior and encourage psychological acceptance. This study is arranged into six main sections: (i) introduction which highlight the gab, statement of problem; (ii) the used methodology in the study; (iii) site selection analysis which present used site in study; (iv) the final design and analysis with application the roles strategies; (v) discussion in term of importance and benefits; and (vi) conclusion and recommendations.

2 Methodology and design principals

The methodology involved designing sustainable homes in a sustainable neighborhood based on providing local residents with renewable energy (solar radiation and wind energy). Five roles were established for the village and serve as the basis of the design methods employed (see Fig. 1). Hence the study will focus in the following objectives;

- Objective one: designing sustainable village in the main gate of Al-Baha region.
- Objective two: application the five roles strategies in sustainable village prototype.
- Objective three: discussing the importance and benefit to addressing urban sustainable roles in future villages and neighborhood.

2.1 Applied architectural design strategies

The architectural design strategies focus on residential units, which will be designed to align with international environmental standards, while also meeting local environmental and cultural requirements. Six main methods were adopted as illustrated in Table 1 below.

The design of the residential units is the key factor affecting energy demand in neighborhoods [9]. Architectural design plays a significant role in energy demand, as well as in how environmental design is embedded into designes [10, 11]. In the proposed design, many strategies are suggested to minimize energy consumption and demand. Firstly reducing

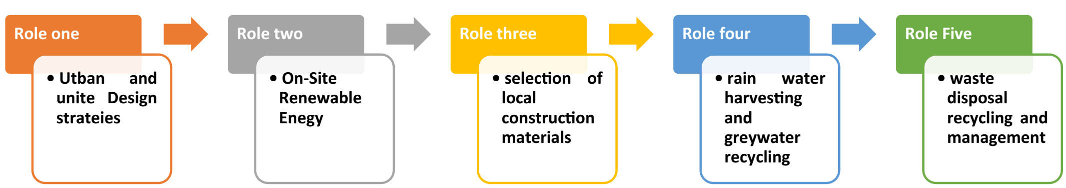


Fig. 1 Sustainable design strategies

Table 1 Architectural design approach

Strategy one	Minimizing unit area
Strategy two	Using a sloping shape and green roofing techniques
Strategy three	Minimizing window areas on south facing walls
Strategy four	Using a one ground basement level instead of a second level
Strategy five	Using building shape (rectangle shape) with a south facing short side
Strategy six	Using semi-detached house and *terrace*s

the unit area allocated based on an average number of occupants, considering the area occupied by typical houses in Saudi Arabia. The allocated area will provide all facilities and meet the household's needs while keeping energy demand to a minimum. Secondly, using a sloping shaped roof will help to limit exposure to direct solar radiation and minimize energy demand. To further assist with cooling, the roof will be covered by grass to insulate the building against the sun's heat, while also facilitating rain water harvesting and the use of photovoltaic panels [12, 13]. Thirdly, the units throughout the neighborhood should minimize winnows and glazed areas, maintaining efficient natural ventilation and lighting [14]. This will help reduce heat transfer through glazed areas. As Saudi Arabia is characterized as having a hot arid climate, the building envelope efficiency should be classified as low heat transference (U-Value). Fourthly, exploiting the basement as a usable floor area plays a significant role in energy saving [15]. As mentioned in many studies, ground heat exchange can provide natural ventilation while conserving as much energy as possible [16, 17] as noted here. Fifthly, using a rectangular shaped design for the unit will make it possible to avoid a south facing orientation and direct solar heat through building shape [18, 19]. Finally, creating semi-detached or terraced units will improve efficiency in the area, and play a significant role in energy saving [20, 21].

2.2 Alternative energy strategies

Exploiting natural energy resources is critical to meet regulatory objectives to provide a sustainable and clean environment. Therefore, macro energy generation and micro energy generation methods were proposed. For strategies supporting on-site renewable energy harvesting see Table 2 below.

Due to the high availability of solar radiation in the southern region of Saudi Arabia [22, 23], exploitation of this natural resource can achieve a clean environment and minimize CO_2 emissions. Photovoltaic (PV) devices will be located on top of all service buildings (e.g., schools, health centers, security station sport centers and other services facilities). The energy generated from solar radiation will be exploited to operate these services, with additional support from energy generated by harvesting wind power. Solar streetlights are also being proposed to operate public lighting throughout the whole neighborhood, with backup systems fueled by wind energy. Thus, to harvest wind energy, it is proposed to locate five wind turbines close to the neighborhood. Residential units will also include PV panels located in car parks and on roofs to harvest solar radiation, covering most of occupants' needs, although it is anticipated additional power will be needed from supply companies.

2.3 Construction materials

To minimize energy use during the construction process, local materials will be used to avoid the extra energy expenditure associated with off-site manufacture and transportation [24, 25]. This can be achieved by manufacturing building elements from locally sourced raw materials. The manufactured materials can be designed to include greater insulation and low thermal transience. Furthermore, designing a building envelope that will slow heat transmission to achieve thermal comfort was a key aim of this project. An efficient building envelope plays a significant role in energy saving [26, 27] in both hot and cold climates. Table 3 below presents the strategies employed when designing the building envelope within the neighborhood, to apply it in all residential units and facilities.

Calculation of the u-value will help to evaluate the efficiency of the building fabric, by determining thermal resistance [28, 29]. Therefore, a calculation of the thermal transference of the building's envelope was made using the equation below:

Table 2 Strategies for gathering on-site renewable energy

Strategy one	Locating five wind power turbined for macro energy generation
Strategy two	Locating PV panels on the top of schools, and other service buildings
Strategy three	Using solar street-lighting poles with conventional flat-plate PV modules
Strategy four	Locating PV panels on top of car parks
Strategy five	Locating PV panels on the top of each residential units

Table 3 Construction materials

Strategy one	Use stone from surrounding mountains to manufacture bricks
Strategy two	Design the building envelope with stone with a thickness of 20 cm
Strategy three	Design the building envelope with a double skin technique with insulation
Strategy four	Design external windows with double glazing and argon gas between them

$$\text{u-value} = \frac{1}{R - Value}; \quad \text{R-value} = \frac{Thickness(m)}{Conductivity}$$

In addition, external windows were designed using efficient double glazing to reduce heat transference through windows while also providing natural ventilation and sun light [30–32].

2.4 Rainwater harvesting and grey water recycling

Many methodologies have been proposed to increase the water supply to residential buildings. One is to engage in rainwater harvesting [33] and greywater recycling. This strategy is important to consider in low energy housing and villages designed around sustainability principals [34, 35]. It is proposed that this project allocate catchment areas for rainwater to be managed and consumed for external purposes, based on the amount of rainwater that can be potentially harvested [36]. Hence, Table 4 presents the rainwater strategies applied.

The calculation for rain water harvesting is dependent on the total catchment area, where the below equation determines potential annual rain water harvesting;

$$\text{Rain water harvesting} = (\text{cachment area}^2) \times (\text{Annual rainfall}) \times (0.9)$$

The roof areas of all residential units should be exploited as catchment areas for rain water. The water harvested will be saved in a specific water tank at each property to exploit this as an alternative water source for outdoor use. This water can be used for external irrigation of private gardens, washing and other uses after filtering. In addition, pathways and public car parks can be used for rain water harvesting and water collected in central water tanks across the village. This water will be used to irrigate public parks and gardens, which may cover over 70% of the land areas of the village. Decentralized urban water recycling systems offer an additional way to collect water for cities. They can help take some of the pressure off the reliance on water supplies from big companies [37]. For private residential units, a greywater recycling system will be introduced with recycled water reused for outdoor purposes.

2.5 Waste disposal recycling and management

One sustainability principle relates to how to integrate waste disposal and consume and manage recyclable waste. When we fail to handle refuse properly, it can contaminate the environment, making people sick [38]. This research offers a framework for waste management and disposal as detailed in Table 5 below.

It is essential to separate household waste, identifying recyclable products, such as cans, tins, papers and others. This approach will support steps towards a cleaner environment. Therefore, allocating colored bins to separate waste in both private units and public locations is important, to achieve efficient waste disposal. Furthermore, central bins can be located around the village to allow waste disposal companies to effectively manage waste removal. Waste will be delivered separately to landfill sites located at least 5 km away from the village. These landfills will handle solid waste in a manner that is environmentally and economically sustainable [39, 40].

Table 4 Water management approach

Strategy one	Designate the roof areas of residential building for rainwater harvesting
Strategy two	Allocate a water tank to each property for rainwater
Strategy three	Designate pathway areas for rain water harvesting
Strategy four	Designate car parks as areas for rain water harvesting
Strategy five	Allocate central water tanks for rain water harvesting
Strategy six	Introduce greywater recycling systems to residential properties

Table 5 Waste disposal management approach

Strategy one	Allocate colored waste bins for private units
Strategy two	Allocate colored waste bins in public locations and gardens
Strategy three	Allocate central colored waste bins in different locations around the villages
Strategy four	Allocate landfills for waste disposal at least 5 km away from the village

3 Environmental site description and analysis

The site is located a few miles from downtown Al Aqiq, and more than 30 miles from both Al-Baha city and Baljurashi city. It was chosen due to its geographical characteristics, and its location close to Al-Baha airport. The Hijaz region experiences damp air fronts that move in from the surrounding plain giving rise to mists and fog. In addition, the range of weather includes thunderstorms, chilly temperatures, and heavy rainfall, with spring and summer months witness moderate temperatures. Figure 2 shows the national scale which reflect the location of Al-Baha region while Fig. 3 shows Al-Aqiq Governorate.

Meanwhile, the commercial sector has a different environment to the Hijaz region. It has moderate winters, and pleasant spring temperatures across the undulating coastal plains. Generally speaking, the Al-Baha region has a dry climate that is warm in summer and relatively cold in winter (Al-Baha municipality website, n.d.). The atmospheric pressure is between 602 and 607, typical temperatures range from highs of 23 to a low of 12, and the average annual rainfall in the Hijaz area varies from 229 to 581 mm, and from 100 to 250 mm in the Tihama sector (Al-Baha municipality website, n.d.). The site was selected taking into account the suitability of the area, its location and the possibility of constructing an environmentally sustainable village meeting the five criteria chosen (see Fig. 4).

The environmental analysis covers the availability of on-site renewable energy, annual rainfall, wind, hours of sunlight and traffic survey. Figure 4 details the site boundary and environmental survey, and Table 6 illustrates the climatic conditions in Al-Baha.

4 Urban environmental design prototype and analysis

The design covers 4,945,000 m^2 and includes the majority of urban facilities and services expected, such as schools, shops, health centers, and open spaces. The aim of the design is to incorporate sustainable strategies to minimize energy demand immediately, starting from the construction of the first residential units. The design contains more than 6150 residential units, and includes private and semi-private open spaces and public open spaces. Furthermore, the design covers schools provision at all levels for both genders, as

Fig. 2 National scale and Al-Baha region (source: [41])

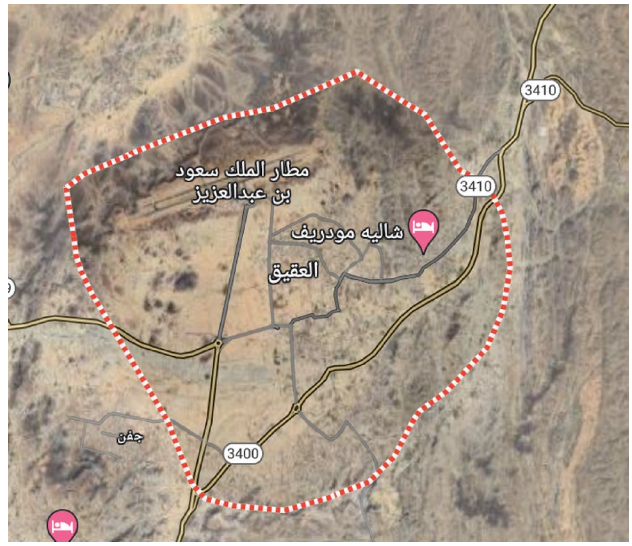


Fig. 3 Al-Aqiq Governorate (source: google earth)

Fig. 4 Site and characteristics (source: google earth)

Table 6 Weather and topographical profile "chemical properties of groundwater for Al-Baha region"

Sampling date	pH	EC_W (dS m^{-1})	Cations (meq L^{-1})				Anions (meq L^{-1})				NO_3^- (mg L^{-1})
			Ca^{2+}	Mg^+	Na^+	K^+	CO_3^-	HCO_3^-	Cl^-	SO_4^-	
August 2016 *	8.01	0.8	1.8	4.3	1.9	0.2	0.0	2.9	4.7	0.7	5.7
August 2020	7.70	1.1	3.1	6.2	2.1	0.3	0.0	1.0	8.5	1.7	4.1

Source: Alghamdi et al. [42]

*Data of year 2016 published by Al-Barakah et al. [54]

Fig. 5 Environmental design layout

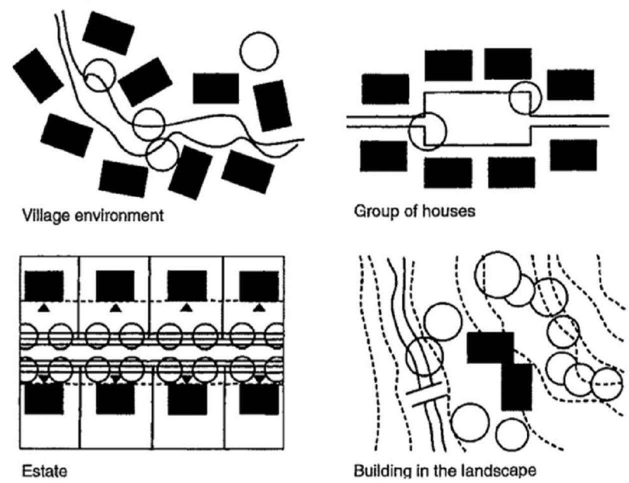


Fig. 6 Cluster design samples (source: Neufert-4th-edition [45])

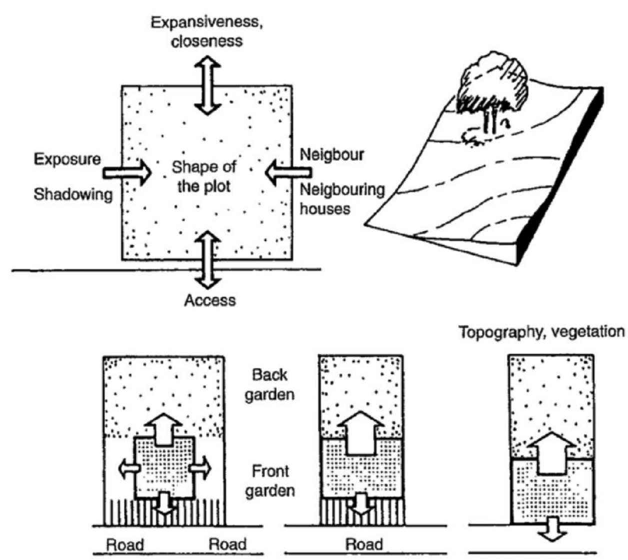


Fig. 7 House location in site (source: Neufert-4th-edition [45])

well as multiple health centers and services. In addition, a private college is proposed to boost the local economy and promote the development. Figure 5 below presents the final land use design plan for the village.

How to plan and design new elements in the city context to improve energy performance and sustainability is the main goal of the study. To analyze complexity, various urban morphological factors were studied, impacting the energy consumption of the entire city [43]. Public Places Urban Spaces provides an in-depth overview of the principles, theory and practices of urban planning, both for newcomers and those who need a clear and systematic guide [44]. The final design of the village has been revised by five experts by providing their comments in application sustainable criteria and exploiting local alternative energy in the line of social needs. Some of the applied methods can be reflected in the design such as; cluster design, open spaces and floor area ration (FAR) but some are described such as the import of construction materials from surrounded mountains and allocated energy stations in macro scale to support the village infrastructure. It is evident that the design concept started with the cluster, and includes many housing and private gardens for each unit. The facilities and services are located in central parks to minimize walking distance for residents and three main central parks.

4.1 Residential and cluster design features

Cluster's design includes the location of the building within its site as well as group of buildings within the cluster to involve its own facility and open space. According to Neufert architecture standards, the Fig. 6 below shows the buildings group "cluster design" sample and its criteria while Fig. 7 presents the unit location within the site.

Each cluster comprises 16 properties, each with privacy and a rear courtyard. Car parks have private entrances within a small area of the building to minimize construction area and use space efficiently. Each house will have its own on-site renewable energy technology to exploit solar radiation and generate electricity. Figure 8 shows the cluster design and description (Table 7).

Each unit area has been designed to keep the indoor area as small as possible, to minimize energy consumption. In addition, the attic roof has been designed as sloping to support rain water harvesting, support the addition of on-site renewable energy collection, and to protect upper floor rooms from the external hot and arid climate by providing an attic space for use as storage and insulation. Figure 4 shows the unit prototype and cluster design. To ensure double-glazed windows perform optimally it is important to enclose the right amount of air between the panes. To achieve this we employed the degree-days method to determine how much air is needed [46]. Windows are responsible for about 60% of energy loss from buildings. Therefore, monitoring window efficiency is important in informing a building's energy requirements [47]. In the literature, *U*-value assessments of windows are usually conducted by implementing theoretical and numerical methods [47]. The double-glazed windows proposed are a vertical rectangular shape that minimizes the glazed area to avoiding solar heating while also providing vital natural ventilation for the dwelling. The residential unit area is about 250 m^2 with an extra 100 m^2 area for the rear private garden and a private allocated car park. Some social challenges may arise when minimizing the area of residential units but in an environmental design, sustainability is the chief concern. Architecturally, the residential units have a high efficiency building envelope including efficiently designed glazing. External windows are rectangular shape with a total area 1.5 m^2 allocated to windows in the property. This will provide necessary sunlight and natural ventilation, while keeping insulation as efficient as possible. Details of the building envelope are provided in Table 8 below.

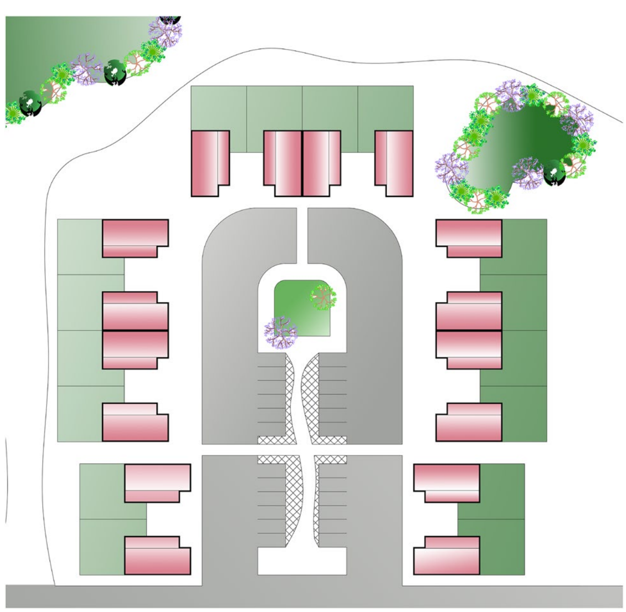


Fig. 8 Cluster design and description

4.2 Application of on-site renewable energy and rain water harvesting

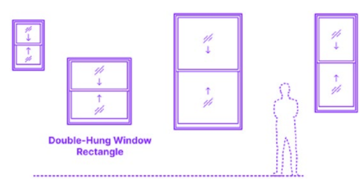
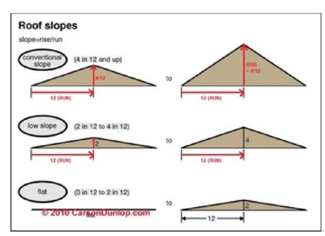
Today, it is widely recognized internationally that the construction sector is one of the main energy consumers. Therefore, interventions in this sector have huge potential to reduce energy consumption and greenhouse gas emissions [48]. Exploiting solar radiation is important in this project, due to availability of natural resources for use as alternative energy. The energy generation from solar radiation has been suggested to using photovoltaic (PV) systems that can generate energy inform of electricity from solar radiation. the amount of this converted energy is vary depending climatic conditions and availability of solar radiation during the year. The average energy generation from solar radiation to energy inform of electricity should exceed 7% of total annual available solar radiation [49, 50]. Hence, the proposed design includes a rooftop solar powered panel system, comprising PV panels covering 20 m^2 for each dwelling. The panels will convert the solar heat to energy in the form of electricity to support the majority of household needs, with any remaining energy requirements met by the Saudi electricity company. Power generation will be between 3000 to 7000 kWh annually, as the solar radiation in the southern region is about 2100 kWh/m^2. The quantity of energy needed to power buildings will be estimated using software simulation tools.

In hot arid countries, interest in rainwater harvesting systems has surged recently due to severe droughts, worries about the impact on the built environment of stormwater runoff, and growing water demand [51]. One significant result is that local legislation and economic restrictions have had a major impact on the level of rain water harvesting system adoption and the chosen technology. Additionally, despite the fact that design guidelines have been established by many nations, suggestions are still sometimes arranged solely with

Table 7 (Land use details) details the areas considered by designers when allocating renewable energy strategies

Site area of the village	4,945,000 m^2	This contains the boundaries and internal road and pathways
Number of residential units	6150 residential units	One type with area less than a typical house in Saudi Arabia to meet environmental requirements
Site area of each residential unit	200 m^2	Area allocated for one family
Building area all floors	250 m^2	The built area including two floors and a roof
Courtyard area	100 m^2	Private courtyard for each house
Area allocated for photovoltaic (P.V) panels	15 m^2	PV has been suggested and oriented as south facing to exploit solar radiation
Area allocated for rain water harvesting	75 m^2	Non-garden area allocated to harvest rain water for reuse
Number of wind turbines suggested	8	Allocated in different locations, not necessarily within the village
Number of public open spaces (parks)	3	Allocated at three main public spaces for social activates
Mosques	5	Two main mosques and three other local mosques
Commercial facilities	More than 40	Allocated at different commercial building and facilities
Schools	6	Allocated at three male schools and an additional three female schools

Table 8 Building envelope description

		Description
Building envelope	Thermal resistance: 0.5 m^2 k/W	
Window area	0.75 m^2 for each window with double glazing argon filled gas	
Window design	Rectangular shape	
Roof design	Sloping roof design	

the aim of water conservation, without taking the possible advantages associated with the numerous functions of rain water harvesting into consideration [52]. In addition, rainwater is typically viewed as a risk rather than as a positive resource when it comes to local water sources [53]. However, a rainwater harvesting system will be implemented for each dwelling taking into account the total roof area of each building, as determined by a simple equation. Rainwater harvesting is one of energy use approach where this been aimed in the study. Rain water harvesting also still depending on annual rainfall in Al-Baha and allocated area of rainwater harvesting (catchment area). The method used is annual rainwater harvesting in the allocated area (– 10%). The average annual rainfall in Al-Baha is 150–200 mm according to [54, 55]. Hence, the annual anticipated rainwater harvesting yield for each dwelling is up to13,500 l, calculated as below:

$$\text{Rain water harvesting} = (\text{cachment area}^2) \times (\text{annual rainfall}) \times (0.9)$$

$$\text{Rain water harvesting} = (75\text{m}^2) \times (200) \times (0.9)$$

Based on this calculation above, a storage tank for rain water will be included with each unit. The harvested water can be used for purposes such as land irrigation, car washing and other outdoor uses.

5 Discussion

Energy conservation is a key component of environmental protection measures. It can be achieved through the efficient design of the built environment from the urban scale to the architectural unit scale. Efficient design includes an urban design with open spaces that encourage walking rather than using vehicles. Many benefits can be attained by applying sustainability principles when developing the Saudi built environment envelope, as discussed below.

5.1 Exploiting alternative resources

Urban designers of villages should seek to address social needs, environmental requirements, topography and on-site renewable resources. This will afford residents access to a healthy environment that is also commensurate with their social needs. The design applied means vehicles need not be used within the village setting, as the entire village has pathways linking key facilities to all residential units. Furthermore, natural resources have been employed to limit CO_2 emissions; i.e., wind energy generation and solar radiation.

According to Peters (2017), environmentally responsible building design will ensure a clean and healthy environment [56]. It important to highlight that, by minimizing the detrimental effects on buildings and to the environment, sustainable design aims to improve the environmental quality of interior spaces [57]. Internationally, designers, developers and decision makers need to consider sustainability when making plans to expand the built environment. This includes reducing the energy demand of buildings through architectural design, building envelope design and exploitation of local renewable resources.

At the planning stages, the environmental design started by determining the specifications for residential units and continued up to the level of the urban design for the entire village. The sloping roof strategy is one of the most significant factors applied in the design, due to the need to integrate a low energy design and on-site renewable energy, as well as rain water harvesting. Furthermore, the open space factor is vital for ensuring natural ventilation and social integration through access to social activities for residents [58, 59]. The final village design considers energy resources, water management and waste disposal management, so as to meet environmental requirements [60] while fulfilling energy demands.

5.2 Economic considerations

The major focus of the research is on environmental friendliness, and the cost of housing stock in light of the changing lived environment. It shows the organization-economic mechanism that informs sustainable development of the dwelling [61]. Hence, improvements to quality of life require sustainable economic improvements [62]. The urban design of the village plays a significant role in economic aspect of Saudi Arabia. Typically, houses are operated annually and rely on burning fossil fuels, which results in high demand in terms of costs to provide energy in form of electricity [63]. It is well known that high levels of energy are consumed by the residential sector. Thus, the energetic causal connections between vitality utilization, vitality cost and financial action in Saudi Arabia necessitates a request side approach [64]. On this basis, developers and consumers should take into account the need to minimize energy demand and favor clean renewable resources.

The sustainability concept has been adopted and acknowledged within the building industry worldwide. However, the significance of social factors have received relatively less consideration [65]. It is essential to issue a sustainable evaluation and develop assessment tools to determine and manage environmental projects in Saudi Arabia. This will make it possible to achieve sustainable development in the residential building industry [66]. A feasible evaluation device can then be created to meet the neighborhood's needs from a social and financial perspective [66, 67]. Current residential buildings can be further developed to minimize energy demand in a way that is sustainable within the local economy. Meanwhile, establishing construction and building materials production firms locally will provide jobs for residents, in a manner that is compatible with Saudi Arabia's Vision 2030 plan.

5.3 Environmental protection

The transition to low CO_2 thermal energy systems requires the provision of concrete information to support both public and private sector decision-making that is future-oriented and optimal in the context of system dependencies [68]. Analysis of ecosystem services can provide quantitative targets for urban ecological revitalization, as determined by the site-specific ecology and climate in urban regions. This is important because the majority of urban ecosystems are currently experiencing significant negative environmental impacts. If cities can provide ecosystem services, then the pressure on surrounding ecosystems can be reduced [69]. Pollution also represents a significant threat to the ecosystem [70, 71]. The Al-Baha region has many forests, which shelter a unique varieties of medicinal plants. These forests are also home to a wide variety of wildlife that needs to being protected to maintain the ecosystem in Al-Baha. Urban sprawl will impact the ecosystem, and higher CO_2 emissions will affect natural plants and wildlife, creating an imbalance in the ecosystem. This will encourage developers to protect forests and construct future buildings in terms of low energy design. In addition, wastewater arising due to the higher number of residential units could disturb the ecosystem. Wastewater from farms, residential housing as well as agro-industrial processing can compromise the integrity of the natural environmental. For environmental protection purposes it is crucial to limit energy consumption when treating wastewater [72].

5.4 Future work: validation

Based on the final design and analysis; the benefits of the sustainable low energy village need to be discussed locally and globally in terms of environmental, social and economic aspects. Hence, this prototype can be applied in future neighborhoods in the built environment in Saudi Arabia, playing a key role in energy saving, and the development of a healthy environment. Computer simulations should be conducted to examine annual energy consumption where energy is being consumed as well as the annual energy generation via PV panels, and annual CO_2 emission rates.

6 Conclusion and recommendations

The study focus is on designing a prototype sustainable low energy village in south western Saudi Arabia, which is characterized by a mountainous topography and a wealth of renewable energy resources. The village design integrates architectural design strategies that are compatible with environmental requirements, and PV panels for each property, with wind energy generation via wind turbines around the village. Furthermore, renewable energy generation has been calculated according the availability of solar radiation and areas where PV panels can be used. Meanwhile, rainwater harvesting and greywater recycling systems strategies have been applied for all residential units, and in some public areas of the village, with annual rainwater harvested based on annual rainfall in the Al-Baha region. Waste management and disposal are taken into account as the design included colored bins for solid recyclable waste and implementation of landfill within five km of from the village. The study concludes with the following recommendations;

1. Design future neighborhoods with sustainable requirements and low energy design.
2. Exploit local natural resources during future building projects, and make it compulsory for all residences to have PV panels.
3. Minimize residential unit area as far as possible while meeting occupants daily requirements.
4. Increase the number of public open spaces within neighborhoods as much as possible, for social and environmental purposes.
5. Establish an environmental method scheme to evaluate village design and with particular emphasis on environmental requirements.
6. Research how best to meet zero-carbon energy demand in the Saudi built environment architecturally and socially and integrate renewable energy generation.
7. Design and construct low energy villages by every city in Saudi Arabia to provide a healthy environment and build public awareness of the importance of low energy villages.
8. Support construction materials factories to avoid the need to import materials to minimize energy expenditure.
9. Use local materials in the built environment to protect the local urban and architectural identity of Saudi Arabia.

Acknowledgements The researchers would like to acknowledge Al-Baha University.

Authors' contributions Only one author for this work: NA conceived the idea, performed all computations and graphing, and wrote the manuscript. Data curation, methodology, resources, software, validation, analysis, writing original, draft writing, review and editing, author has read and agreed to the submitted version of the manuscript.

Funding This research is part of a project funded by Al-Baha University, KSA (Grant No. 1440 /25).

Availability of data and material Data will be available on request to corresponding author.

Declarations

Conflict of interest The author declares no conflict of interest.

References

1. Shi Q et al (2016) Challenges of developing sustainable neighborhoods in China. J Clean Prod 135:972–983
2. Zhao X, Yin H, Zhao Y (2015) Impact of environmental regulations on the efficiency and CO_2 emissions of power plants in China. Appl Energy 149:238–247
3. Binsaedan L, Alshuwaikhat HM, Aina YA (2023) Developing an urban computing framework for smart and sustainable neighborhoods: a case study of Alkhaledia in Jizan City, Saudi Arabia. Sustainability 15(5):4057
4. Ahmed AR, Al-saud KA (2016) Towards Environmental Sustainable Neighborhoods in Riyadh City. In: Int'l Conference of 5th International Conference on Advances in Engineering and Technology (ICAET'2016)
5. Rafique MM, Rehman S, Alhems LM (2018) Developing zero energy and sustainable villages–a case study for communities of the future. Renewable Energy 127:565–574
6. Zande RV (2010) Creating the urban village: teaching pre-service teachers about sustainable design in architecture and community planning. Int J Art Des Educ 29(3):321–329
7. Kim K-B (2005) Towards sustainable neighborhood design: a sustainability evaluation framework and a case study of the Greenwich Millennium village project. J Architect Plan Res 181–203
8. Agustin SA (2020) The development of sustainable village design model using educative graphic mural on community's environmental responsibility through the application of participatory design method. In: International Joint Conference on Arts and Humanities (IJCAH 2020). Atlantis Press
9. Nguyen TTT (2022) Architectural design guideline for sustainable floating houses and floating settlements in Vietnam. WCFS2020. Springer, pp 461–474
10. El Demery IM (2010) Sustainable architectural design: reviving traditional design and adapting modern solutions. ArchNet-IJAR 4(1)
11. Bondars E (2013) Implementing bioclimatic design in sustainable architectural practice. Arch Urban Plan 7:84–86
12. Sheng LX et al (2011) Integrated sustainable roof design. Procedia Eng 21:846–852
13. Ugai T (2016) Evaluation of sustainable roof from various aspects and benefits of agriculture roofing in urban core. Procedia Soc Behav Sci 216:850–860
14. Thomsen KE (2007) Advanced energy efficient windows. In: Guidelines-BRITA-IN-PuBS. Brita-in-pubs, Fraunhofer Institute of Building Physics
15. Andolsun S et al (2011) EnergyPlus vs. DOE-2.1 e: the effect of ground-coupling on energy use of a code house with basement in a hot-humid climate. Energy Build 43(7):1663–1675
16. Oh K et al (2019) Field experiment on heat exchange performance of various coaxial-type ground heat exchangers considering construction conditions. Renewable Energy 144:84–96
17. Flaga-Maryanczyk A et al (2014) Experimental measurements and CFD simulation of a ground source heat exchanger operating at a cold climate for a passive house ventilation system. Energy Build 68:562–570
18. Pathirana S, Rodrigo A, Halwatura R (2019) Effect of building shape, orientation, window to wall ratios and zones on energy efficiency and thermal comfort of naturally ventilated houses in tropical climate. Int J Energy Environ Eng 10(1):107–120
19. Monteiro H, Freire F, Soares N (2021) Life cycle assessment of a south European house addressing building design options for orientation, window sizing and building shape. J Build Eng 39:102276
20. Bjarløv SP, Vladyková P (2011) The potential and need for energy saving in standard family detached and semi-detached wooden houses in arctic Greenland. Build Environ 46(8):1525–1536
21. Sobhy I, Brakez A, Benhamou B (2017) Analysis for thermal behavior and energy savings of a semi-detached house with different insulation strategies in a hot semi-arid climate. J Green Build 12(1):78–106
22. AlYahya S, Irfan MA (2016) Analysis from the new solar radiation Atlas for Saudi Arabia. Sol Energy 130:116–127
23. Mohandes M, Rehman S (2010) Global solar radiation maps of Saudi Arabia. J Energy Power Eng 4(12):57–63
24. Cabeza LF et al (2013) Low carbon and low embodied energy materials in buildings: a review. Renew Sustain Energy Rev 23:536–542
25. Doh J-H, Panuwatwanich K (2014) Variations in embodied energy and carbon emission intensities of construction materials. Environ Impact Assess Rev 49:31–48
26. Zhou Z et al (2018) Heating energy saving potential from building envelope design and operation optimization in residential buildings: a case study in northern China. J Clean Prod 174:413–423
27. Al-Yasiri Q, Szabó M (2020) Incorporation of phase change materials into building envelope for thermal comfort and energy saving: a comprehensive analysis. J Build Eng 2020:102122
28. Andújar Márquez JM, Martínez Bohórquez MÁ, Gómez Melgar S (2017) A new metre for cheap, quick, reliable and simple thermal transmittance (U-Value) measurements in buildings. Sensors 17(9)
29. Bienvenido-Huertas D et al (2019) Applying an artificial neural network to assess thermal transmittance in walls by means of the thermometric method. Appl Energy 233:1–14
30. Michaux G et al (2019) Modelling of an airflow window and numerical investigation of its thermal performances by comparison to conventional double and triple-glazed windows. Appl Energy 242:27–45
31. Fang Y et al (2020) Solar thermal performance of two innovative configurations of air-vacuum layered triple glazed windows. Renewable Energy 150:167–175
32. Gloriant F et al (2015) Modeling a triple-glazed supply-air window. Build Environ 84:1–9
33. Abdulla FA, Al-Shareef AW (2009) Roof rainwater harvesting systems for household water supply in Jordan. Desalination 243(1–3):195–207
34. Pachpute J et al (2009) Sustainability of rainwater harvesting systems in rural catchment of Sub-Saharan Africa. Water Resour Manag 23(13):2815–2839
35. Che-Ani A et al (2009) Rainwater harvesting as an alternative water supply in the future. Eur J Sci Res 34(1):132–140
36. Aladenola OO, Adeboye OB (2010) Assessing the potential for rainwater harvesting. Water Resour Manag 24(10):2129–2137
37. Wanjiru E, Xia X (2017) Optimal energy-water management in urban residential buildings through grey water recycling. Sustain Cities Soc 32:654–668
38. Odonkor ST, Frimpong K, Kurantin N (2020) An assessment of house-hold solid waste management in a large Ghanaian district. Heliyon 6(1):e03040

39. Mazzanti M, Zoboli R (2008) Waste generation, waste disposal and policy effectiveness: evidence on decoupling from the European Union. Resour Conserv Recycl 52(10):1221–1234
40. Costa AM, Alfaia RGDSM, Campos JC (2019) Landfill leachate treatment in Brazil—an overview. J Environ Manag 232:110–116
41. Anne Eilenberg HSA, Costanza La M, Rama N, Anne K-A, Samuel N, Faisal BS, Giuseppe T, Elizabeth G, Mazen M, Solomon K (2019) Future Saudi Cities Programme City Profiles Series: Al Baha. Ministry of Municipal and Rural Affairs King Fahd National Library Cataloging-in-publication Data
42. Alghamdi AG, Aly AA, Ibrahim HM (2022) Effect of climate change on the quality of soil, groundwater, and pomegranate fruit production in Al-Baha Region, Saudi Arabia: a modeling study using SALTMED. Sustainability 14(20):13275
43. Manesh SV, Tadi M (2011) Sustainable urban morphology emergence via complex adaptive system analysis: Sustainable design in existing context. Procedia Eng 21:89–97
44. Carmona M (2021) Public places urban spaces: the dimensions of urban design. Routledge, London
45. Neufert E, Neufert P (2012) Architects' data. Wiley, New York
46. Arıcı M, Karabay H (2010) Determination of optimum thickness of double-glazed windows for the climatic regions of Turkey. Energy Build 42(10):1773–1778
47. Cuce E (2018) Accurate and reliable U-value assessment of argon-filled double glazed windows: a numerical and experimental investigation. Energy Build 171:100–106
48. Missoum M et al (2016) Impact of a grid-connected PV system application in a bioclimatic house toward the zero energy status in the north of Algeria. Energy Build 128:370–383
49. Rehman S, Bader MA, Al-Moallem SA (2007) Cost of solar energy generated using PV panels. Renew Sustain Energy Rev 11(8):1843–1857
50. Pavlović T et al (2013) Possibility of electricity generation using PV solar plants in Serbia. Renew Sustain Energy Rev 20:201–218
51. Jones MP, Hunt WF (2010) Performance of rainwater harvesting systems in the southeastern United States. Resour Conserv Recycl 54(10):623–629
52. Campisano A et al (2017) Urban rainwater harvesting systems: Research, implementation and future perspectives. Water Res 115:195–209
53. Domènech L, Saurí D (2011) A comparative appraisal of the use of rainwater harvesting in single and multi-family buildings of the Metropolitan Area of Barcelona (Spain): social experience, drinking water savings and economic costs. J Clean Prod 19(6–7):598–608
54. Al-Barakah FN et al (2020) Comparison and hydrochemical characterization of groundwater resources in the Arabian Peninsula: a case study of Al-Baha and Al-Qassim in Saudi Arabia. Water Resour 47:877–891
55. Alghamdi AG et al (2023) Impact of climate change on hydrochemical properties and quality of groundwater for domestic and irrigation purposes in arid environment: a case study of Al-Baha region, Saudi Arabia. Environ Earth Sci 82(1):39
56. Peters T (2017) Superarchitecture: building for better health. Archit Des 87(2):24–31
57. Iwaro J, Mwasha A (2013) The impact of sustainable building envelope design on building sustainability using integrated performance model. Int J Sustain Built Environ 2(2):153–171
58. Malek NA, Nashar A (2018) Use pattern and activities: the evaluation of Malaysian green open space design. Plan Malays 16(7)
59. Huang J et al (2016) Outdoor thermal environments and activities in open space: an experiment study in humid subtropical climates. Build Environ 103:238–249
60. Masoud AA (2020) Renewable energy and water sustainability: lessons learnt from TUISR19. Springer, New York
61. Safronova N, Nezhnikova E, Kolhidov A (2017) Sustainable housing development in conditions of changing living environment. In: MATEC web of conferences, EDP Sciences
62. Rosilawati H, Setijanti P, Noerwasito VT (2016) Community economic improvement on flats based on sustainable housing concept. Int J Eng Res 5(1):2–45
63. Martínez CIP et al (2021) Trends and dynamics of material and energy flows in an urban context: a case study of a city with an emerging economy. Energy Sustain Soc 11(1):1–15
64. Alshehry AS, Belloumi M (2015) Energy consumption, carbon dioxide emissions and economic growth: the case of Saudi Arabia. Renew Sustain Energy Rev 41:237–247
65. Fatourehchi D, Zarghami E (2020) Social sustainability assessment framework for managing sustainable construction in residential buildings. J Build Eng 32:101761
66. Zhe YW, Hayder G (2019) Developing an assessment tool for sustainable and green project management. In: International conference on dam safety management and engineering, Springer, New York
67. Ding GK (2008) Sustainable construction—the role of environmental assessment tools. J Environ Manag 86(3):451–464
68. Diran D et al (2020) A data ecosystem for data-driven thermal energy transition: Reflection on current practice and suggestions for re-design. Energies 13(2):444
69. Pedersen Zari M (2017) Biomimetic urban design: ecosystem service provision of water and energy. Buildings 7(1):21
70. Escobedo FJ, Kroeger T, Wagner JE (2011) Urban forests and pollution mitigation: Analyzing ecosystem services and disservices. Environ Pollut 159(8–9):2078–2087
71. Freedman B (2013) Environmental ecology: the impacts of pollution and other stresses on ecosystem structure and function. Elsevier, Amsterdam
72. Abrahams JC et al (2017) The brookside farm wetland ecosystem treatment (WET) system: a low-energy methodology for sewage purification, biomass production (yield), flood resilience and biodiversity enhancement. Sustainability 9(1):147