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Establishing Domestic Low Energy Consumption Reference Levels For Saudi Arabia And The Wider Middle Eastern Region

Naief A. Aldossary, Yacine Rezgui, Alan Kwan

Abstract

Saudi Arabia is renowned for its full reliance on fossil fuel energy and lack of an energy regulatory framework for its built environment. The paper focuses on the domestic sector and aims to: (a) establish levels of energy reduction, informed by leading standards (such as Passivhaus in Germany), that can be achieved taking into account the complex local socio-cultural context and environmental factors, and (b) propose a low energy reference definition with a view of encouraging energy retrofitting programs and enforcing domestic low carbon interventions. An energy simulation environment is employed to simulate and analyze energy consumption patterns of three proposed low carbon prototype houses that reflect current house typology and space layout in the country. The three proposed homes offer a reduction in energy consumption of up to 71.6%, compared with similar houses. Based on these findings, a domestic energy performance reference is proposed with energy consumption ranging between 77 kWh/m2 and 98 kWh/m2. Economic and environmental benefits are discussed as well as recommendations for enforcing low carbon design in the country and across the region.

Keywords: low carbon design, domestic sector, energy conservation, energy performance

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1 Introduction

The residential sector in Saudi Arabia is renowned for its high energy consumption and CO_2 emission rates [1-3]. Domestic sector is the largest consumer of electrical energy (over 50%), and as such, represents a major potential to reduce energy consumption and CO_2 emissions [4]. Natural resources, i.e. solar and wind energy, are abundant in the Kingdom [5-7]. This potential is not exploited as electricity is exclusively generated using burning fossil fuel, responsible for high rates of CO_2 emissions [8, 9]. Many developed countries have addressed the need to reduce energy by developing environmental assessment frameworks and sustainable construction codes and regulations, that factor in local climatic conditions. However, no such regulatory framework is in place and enforced in Saudi Arabia [10, 11].

Controlling Energy consumption for domestic sector forms an important step for decision makers. Many developed countries have followed this path, establishing a definition standard of energy consumption based on: (a) climatic conditions; (b) the needs of citizens; (c) the availability of construction materials. The level of low energy consumption differs between countries, based on existing environmental challenges. It is not possible to employ the definition standard from one country to another, due to differences in climatic conditions. Saudi Arabia has a hot climate, with a tendency for large buildings with a high degree of energy consumption for cooling. Energy consumption can be reduced to a minimum while still fully servicing inhabitants' needs as far as possible. A specific energy consumption definition standard could manage and regulate the energy consumption for the housing sector, based on need, availability of construction materials and climatic conditions.

2 Aim of the study

The primary aim of the current study is to assess and establish an energy consumption definition standard for housing in Saudi Arabia (in the form of kWh/m2). This will require an in-depth investigation to identify the minimum needs of energy in the domestic sector on the basis of need (i.e. activities and the climate of Saudi Arabia). Hence, The paper aims to: (a) establish levels of domestic energy reduction, informed by leading standards (such as Passivhaus in Germany), that can be achieved taking into account the complex local socio-cultural context and environmental factors, and (b) propose a low energy reference definition with a view of encouraging energy retrofitting programs and enforcing domestic low carbon interventions. Following this introduction, Chapter 2 summarizes related research and low carbon definitions. This is followed by the underpinning methodology. The proposed low energy houses are then described, simulated, and analyzed. Finally, a proposal for low energy homes is discussed as well as the required energy policy framework.

3 Related work

The EU is fully engaged in implementing staged energy and CO_2 reduction targets [12-15]. In 2008, a survey across Europe identified seventeen different terms in use to describe low energy domestic Houses [16]. These include: passive house, low energy house, high performance house, zero energy house [17], energy saving house, energy positive house, and 3-litre house. The literature on this subject also uses the terms ultra-low energy house, eco-house and green house [16].

At present, seven European Member States have adopted a working definition of a low energy House. These definitions are most often applied to new Houses, but also cover existing Houses, and can usually apply to both residential and non-residential buildings. The required reduction in energy consumption normally ranges from 30% to 50%, depending on the specificity of the proposed design. This generally corresponds to an annual demand for energy ranging from 40 to 60 kWh/m2 in central Europe. Terms have been introduced in some European countries (for example MINERGIE in Switzerland, and Effinergie in France) to help occupants identify the national standard for low energy Houses [16]. An overview of definitions for low energy Houses across Europe is given in Table 3.1:

Country	Official definition
Austria	▪ Energy consumption from heating systems in low energy Houses should be below 60-40 KWh/m2 per year. ▪ The standard for a passive house is 15 kWh/m2 per useful area (Styria) and per heated area (Tyrol)
Belgium (Flanders)	▪ Class 1 for low Energy houses is 40% lower than for standard houses ▪ Class 2 for very low Energy houses means a 60% reduction in energy
Czech Republic	▪ The energy consumption of a low energy house is: 51 – 97 kWh/m2 p.a. ▪ The energy consumption of a very low energy house is below 51 kWh/m2 p.a. ▪ The standard of a passive house is 15 kWh/m2 per year
Denmark	▪ Class 1 for a Low Energy house calculates energy an performance at 50% lower than the minimum requirement for new Houses ▪ Class 2 for a low Energy house calculates the energy performance at 25% lower than the minimum requirement for new Houses.
Finland	▪ The standard of low energy houses is 40% better than that of standard Houses
France	▪ New houses - the average annual energy consumption for domestic applications such as heating/cooling systems, ventilation, hot water and lighting must be lower than 50 kWh/m2. (From 40 to 65 kWh/m2) based on the climatic conditions ▪ Other houses - the average annual energy consumption for heating/cooling systems, ventilation, hot water and lighting must be 50% lower than current House Regulation requirements for new Houses. ▪ For renovations: 80 kWh/m2 as of 2009
Germany	▪ The requirements for consumption of low Energy Houses in the residential sector are 60kWh/(m2•a) or (40 kWh/(m2•a) ▪ Passive Housing - the annual heating demand is lower than 15 kWh/m2 and total energy consumption is lower than 120 kWh/m2
England & Wales	▪ 2010 level 3 (25% better than current regulations) ▪ 2013 level 4 (44% better than current regulations and almost similar to Passive House) ▪ 2016 level 5 (zero carbon for heating and lighting) ▪ 2016 level 6 (zero carbon for all uses and appliances) [18]

Table 3.1- Source: SBI (Danish House Institute), European Strategies to move towards very low energy Houses, 2008. [19]

In this context, it is difficult to define exactly what can be termed a low energy House given the variety of regulations and climates across Europe and beyond (including US) [16]. Moreover, what is considered a low energy development in one country may not meet local definitions in another [16]. An example of this is the Energy Star label in the US, which is awarded to Houses that use 15% less energy than what regulations call for in typical new homes [16].

In a zero energy house, all energy needs are fully provided for by renewable carbon free energy sources . Zero energy houses can be self-sufficient, never drawing power from the energy grid supply. However, more frequently, they balance power consumption from the grid with energy production that is returned to the grid as renewable energy sources often vary seasonally [20]

Aldossary et al. (2013) [21, 22] have discussed patterns of energy consumption in multiple case studies across Saudi Arabia. They have investigated energy demand from: (1) domestic stock in a hot arid climate, taking Riyadh city as case study; and (2) a hot humid climate, taking Jeddah city as case study. They have validated the energy use by employing IES-VE simulation tools, and comparing the result with actual electricity bills. They highlight that: (1) there is a considerable amount of energy and high Co2 emission rate where the bulk of energy is used in a cooling system. They suggest a number of limited solutions for the building of housing to reduce energy demand by up to 37%. Alnatheer (2006) has undertaken an evaluation of the environmental impact of the expansion of the electrical system in the Kingdom of Saudi Arabia. He demonstrates the ways in which renewable energy and energy-efficient sources can be employed to generate clean and optimised energy (i.e. in the form of electricity) [23]. Shafiqur Rehman et al. (2007) have studied the distribution of radiation and sunshine by duration across Saudi Arabia, establishing a marked difference in solar radiation between different regions: from 1.63MWh/m^2 yr–1 at Tabuk (i.e. a northern region) to

2.56MWh/m² yr–1 at Bisha (i.e. a southern region). They add that Photovoltaic (PV) technology has been proven to be a simple and effective means of generating electricity through solar energy [2]. Ali et al. [24] have provided a more specific example of the exploitation of natural resources, through a demonstration of the functioning of an automated irrigation system by means of PV modules.

4 Methodology

This study is informed by established low carbon domestic design standards and frameworks as summarized in Table 3.1. The Ministry of Municipality states that the housing requirements leading to the issue of a permit of construction contain a number of conditions, related in particular to issues of privacy and architectural design (i.e. height of buildings and the building area). From this perspective, there are no conditions in place concerning environmental requirements and energy conservation as an important responsibility. Housing in Saudi Arabia must meet the following: (a) the client's requirements and budget; (b) environmental requirements; and (c) cultural requirements. Saudi Arabia has a hot climate, leading to the housing sector consuming a considerable amount of energy (the Ministry of Electricity states this to be over 50% of energy), which must be controlled by official certificates and energy definition standards. An individual house can be designed to have limited energy consumption in relation to the number of household members. This leads to the importance of establishing an energy consumption definition for the Saudi Arabian climate and the needs of its population. Many countries have now issued their own energy consumption definition standard to reflect their energy needs and assist with energy conservation.

The proposed interventions will focus on: (a) architectural design (massing and space layout), (b) house envelope (fabric), and (c) on-site renewable energy strategies. Moreover, three proposed house prototypes will be assessed with respect to their predicted energy performance. The study is underpinned by the following research questions:

1) What levels of domestic energy demand reduction can be achieved based on local environmental conditions, socio-cultural requirements, and occupants' comfort needs?

2) How resulting energy performance compare with existing standards in developed countries?
3) How to enforce these measures given the complex Saudi energy landscape?

One of the challenges of this research is creating design interventions acceptable by the general public in Saudi Arabia. Socio-cultural and religious practices dictate particular spatial arrangements such as separate guest rooms (reception rooms) for males and females [21, 25, 26]. Moreover, Saudi families are quite large (often with complex family structures) requiring large spaces to meet their needs. Another challenge is how to persuade people to prioritize sustainability as a driving criterion for their home design? Evidence suggests that Saudis prefer to live in large houses to accommodate their large families and / or to exhibit a social status symbol [26, 27].

Three prototype houses are proposed reflecting current socio-cultural requirements. It is important to note that these three prototype designs do not reflect the most efficient low energy design possible in Saudi Arabia, and are employed purely as a sample to establish a definition of an energy consumption standard for the hot climate of Saudi Arabia. The level of energy consumption achieved in this study is flexible, enabling the client to achieve a lower level, if possible, depending on whether the available budget is sufficient to allow for: (1) the design of a more efficient insulated building envelope; (2) more efficient environmental and architectural standards; and (3) apply a larger area of onsite renewable energy (i.e. PV). The identified level of definition standards can be achieved by the client, and can be flexible when it comes to their application in Saudi Arabia, so as to manage and control energy conservation and meet the relevant clean sustainable building and environment economical goals.

These prototypes are of decreasing sizes, enhanced from a space layout, fabric and renewable energy integration:

- **House Prototype1:** This design reflects current Saudi large houses and is as such suitable for a large family. It is designed to optimize energy efficiency by enhancing the envelope (including openings), using shading devices where appropriate, and integrating on-site renewable solutions.
- **House Prototype 2:** This prototype aims at families with fewer occupants and willing to reduce their energy footprint. It is medium-sized compared with typical Saudi houses. Similar energy efficient interventions are applied as to prototype 1.
- **House Prototype 3:** This conveys the most energy efficient design taking into account the Saudi socio-cultural and environmental conditions, with lesser living space.

This research follows on from related studies that have successfully utilised simulation tools, including IES-VE, to establish an energy profile of a given house / building [28]. A Building Information Model (BIM) is developed for each house prototype. As indicated earlier, all designs focus on: (a) massing and space layout, (b) envelope, including construction materials used for external walls, roof, floor and external glazing, (c) on-site renewable energy strategies, and (d) user profiling (of the occupants), informed by earlier studies [21, 25]. The main outputs from the energy simulation are: (a) estimates of annual energy consumption in kWh and in kWh/m2 and (b) CO_2 emission rates. Also, energy consumption is calculated hourly throughout the year, including for each season. A profiling of energy use is also provided, including air conditioning, lighting, domestic hot water (DHW), and white goods.

5 Proposed Low Energy Houses for The Saudi Climate

Three different prototype low energy houses are proposed informed by earlier research [21, 25], and detailed below.

5.1 House Prototype1

This house is designed in line with current living space area of typical domestic homes in Saudi Arabia, as permitted by the planning consent authority (i.e. Ministry of municipality). The architectural drawings are illustrated in Fig 5.1, while Table 5.1 summarizes key design area figures.

Fig 5.1- Layout Design of House Prototype1

Ground Floor Area	200.4 m2	**External Walls Area**	487.7 m2
First Floor Area	175.5 m2	**Total Windows Area**	39 m2
Second Floor Area	49.7 m2	**Total Volume of the House**	1277.4 m3
Total House's Area	425.8 m2	**PV Area**	60 m2

Table 5.1 Area description of house prototype1

This house can accommodate many family members and is designed with some energy conservation measures. The design can support all human activities and meets 100% of Saudi socio-cultural requirements [21, 25].

5.1.1 Architectural design techniques

There is an abundant literature on low carbon interventions in the domestic sector [29-31]. The design interventions of prototype1 draw on these techniques as summarized below.

- ***Massing and space layout:*** The design aims to reduce the area of windows ensuring sufficient natural light, especially in south facing rooms [32, 33]. Also, the area of some rooms has been reduced, such as bedrooms, to lower energy demand, while still meeting socio-cultural requirements.
- ***Shading Device techniques:*** shading devices play an important role in energy saving in hot climates, helping to reduce the overall cooling energy demand [34-37]. The first design intervention involved a sloping roof acting as a shading device on top of the House to protect the external roof from solar heat and reduce its temperature. Further shading devices were added on top of each window to prevent and reduce solar heat. Also, additional shading devices were added to the top of the surrounding walls that many people in Saudi Arabia construct for privacy purposes. Additional canopies were installed at the top of each storey with a 0.7m depth to provide additional shading.

5.1.2 On-site renewable energy

It is known that onsite renewable energy can reduce energy by utilising natural resources to generate electricity, rather than the burning of fossil fuels [38-40]. This depends on the availability of the required solar radiation, along with the location, as these dictate the potential to cover the needs of the occupants. Based on the case study analysed, there are at present no renewable energy systems capable of generating electricity and reducing Co2 emissions. According to [2], *the solar radiation available in Saudi Arabia can reach up to 2190 kwh/ m^2.* This represents an abundant natural energy resource that could be used in place of the burning of fossil fuels, thus saving money and reducing CO2 emissions. 10% to 15% of solar radiation can be generated as electricity, and therefore solar panels (i.e. PV) have been installed on the eastern and western orientation on no more than 35% of the total roof area. The electricity generated will be used to heat DHW, and support air conditioning systems, which account for 75% of the energy consumption of a typical Saudi house [21, 25].

5.1.3 House envelope design

The design of the house envelope plays a significant role in reducing energy demand [41-43]. Selection of construction materials is informed by local environmental conditions [44]. As Saudi Arabia has hot and extreme environment for the majority of the year, it is important to design the envelope of the House with high thermal resistance to prevent or slow down heat transfer from the external to indoor environment. This will reduce the air conditioning load needed to achieve a satisfactory comfort level for occupants.

The approach used to measure the performance of the house envelope is through its thermal resistance [45]. ISO 9869 standards are normally followed for the in situ measurement of thermal resistance as well as the thermal transmittance of the house envelope [46-49]. The thermal transmittance of the house envelope (U value in W/m2K) is measured as [50]:

$$U = \frac{1}{R_{\mathrm{T}}},$$

where R_T is the total thermal resistance (in m2 K/W) of the construction materials used. This can be measured as:

$$R_{\mathrm{T}} = R_{\mathrm{si}} + R + R_{\mathrm{se}},$$

R_{si}: is the internal thermal resistance of the house envelope

R_{SE}: is the thermal resistance of external surface of the house envelope. The thermal resistance of the individual layer can be calculated by the theory below:

$$R = \frac{\lambda}{d},$$

where (λ) is the thermal conductivity (in W/m K) of the insulation materials used in the house envelope and (d) is the thickness (in meter) of each material used.

Table 5.2 below provides the details of the construction materials used for the envelope. The U-Value or R-Value is important to determine the efficiency of the house's envelope. The optimum design of House fabric (thermal insulation) plays a major role in reducing energy demand [41-43, 51]. As illustrated in Table 5.2, the U-value for the external walls or roof was not more than 0.34 W/ m2 k. A triple glazing system with a cavity filled with argon gas was used to reduce the transmission of direct-beam solar irradiation, reduce the heat gains from the ambient environment, and maintain adequate levels of daylighting [52, 53].

House Envelope	**Construction Materials Used**	**Thicknesses**	**U-Value W/ m² k**	**R-Value m² k/ W**
External Walls	Vermiculite Insulating Brick, insulations materials and Brick worker	45 cm	0.345	2.72
Roof	Roof tiles, insulations and concretes	55 cm	0.194	5.01
Floor	Stone, concretes, insulations, sand and Mortar	80 cm	0.7	0.97
Internal partitions	Plaster, Brickworks and Plaster	13 cm	1.6	0.33
Ceilings	Cast Concrete (DENSE) and Carpet	11 cm	2.28	0.238
External Windows	Triple Glazing with cavities filled with argon gas		1.72 (Glass only)	

Table 5.2- Design Description of the House Envelop for House Prototype1

5.2 House Prototype2

This house was designed differently from house prototype1 in its detail and techniques as elaborated below.

5.2.1 Architectural Design techniques

The massing and space layout involves smaller areas compared with a typical house in Saudi Arabia. The House is designed with a rectangular depth to avoid southern solar heat. The details of the architectural design are illustrated in figure 5.2.

Fig 5.2- Layout Design of House Prototype2

Window areas are reduced to provide just required natural light. It is worth noting that the southern elevation does not have windows, eastern or western oriented windows are provided instead. Table 5.3 presents the area description of house prototype2.

Ground Floor Area	114.8 m2	**External Walls Area**	357.5 m2
First Floor Area	114.8 m2	**Total Windows Area**	18.6 m2
Second Floor Area	28 m2	**Total Volume of the House**	772.9 m3
Total House's Area	257.6 m2	**PV Area**	40 m2

Table 5.3 Area description of house prototype2

Shading devices are installed in the house using (a) external shutters to prevent or slow solar heat transfer. An additional shading device is installed at the top of each window; (b) as Saudi Houses have an external surrounding wall for privacy purposes, an external device is installed on the top of the wall at a height of 7 meters; and (c) the sloping roof technique is used to prevent solar heat reaching the ceilings in the top floor rooms. Each external window is equipped with an internal shutter. In addition, the shutters are insulated and painted in a dark colour.

5.2.2 On-site renewable energy

Similar to house prototype1, prototype 2 involves the use of PV panels. The sloping roof, to the east and west, provides the ideal location for PV panels. The total area of the roof is 114.8 m2, 40 m2 of which is allocated to PV panels. The energy generated will then be used to operate the air conditioning and heat up the DHW [21, 25].

5.2.3 House envelope design

The house envelope uses a double skin for the external walls. For the basement floor, several layers of stone and efficient construction materials are selected. Triple glazing with argon gas is used in the external windows to increase their R-Value. Table 5.4 presents the house envelope design for the house, including material specification.

House Envelope	Construction Materials Used	Thicknesses	U-Value W/ m² k	R-Value m² k/ W
External Walls	Brickwork, EPS slab insulation, polyurethane board, and inner Brickwork	30 cm	0.257	3.70
Roof	Roof felt, Felt insulation material, mineral fibre slab, cast Concrete (Light Weight), Cavity Insulation (ASHRAE) and ceiling mortar	46.5 cm	0.237	4
Floor	Stone, Cast Concrete (Light Weight), Sand, dens EPS Slab Insulation and clay tiles	76 cm	0.104	8.4
Internal partitions	Plaster and Brickworks and Plaster	13 cm	1.6	0.33
Ceilings	Cast Concrete (DENSE), Mortar and Carpet	11 cm	2.28	0.238
External Windows	Triple Glazing with cavities filled with argon gas		1.72 (Glass only)	

Table 5.4- Design Description of the House Envelop for House Prototype2

5.3 House Prototype3

This housing design is intended for a small family, keeping the living area to a minimum. The design is dramatically different from both the current housing style in Saudi Arabia and the other house types designed in this study. The socio-cultural aspects are overlooked (a western style space layout is used) to demonstrate optimal energy reduction.

5.3.1 Architectural Design techniques

The massing and space layout is smaller compared to the two previous prototypes. It is laid out simply over two floors with a sloping roof to allow for an attic space. The layout plan is shown in figure 5.3.

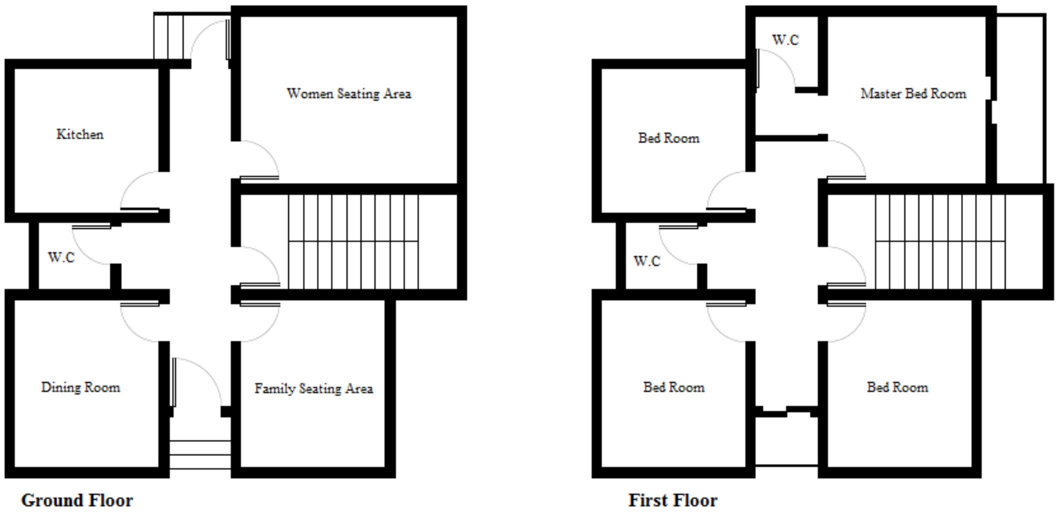


Fig 5.3- Layout Design of House Prototype3

This house is oriented in a northerly direction to avoid the impact of solar heat as much as possible. The attic contains two rectangular windows on the east and west elevation to allow natural ventilation at night. These will be closed during the day to create a cooler space between the sloped roof and the ceiling on the top floor. The sizes of the rooms are minimized as much as possible to avoid extra space, which neither adds value nor reduces energy consumption, while still meeting the occupants' needs. As with the other house prototypes, this design avoids south-facing windows and reduces their area to 0.75m2. Table 5.5 shows the details of the area description of house prototype3

Ground Floor Area	67.7 m2	**External Walls Area**	229.3 m2
First Floor Area	64.6 m2	**Total Windows Area**	12.4m2
Attic Area	64.6 m2	**Total Volume of the House**	397.1 m3
Total House's Area	132.3 m2	**PV Area**	30 m2

Table 5.5 Area description of house Prototype3

The Facade brace technique is used as a shading solution. This allows natural ventilation on the southern façade to reduce air conditioning load. Additional shading devices are installed on top of each window to prevent solar radiation reaching the external glazing. Additional external shutters are installed for each window to prevent solar heat reaching the windows during the hottest periods of the day. To maximize insulation, dark insulated curtains are installed.

5.3.2 On-site renewable energy techniques used

This house is smaller than the two other prototypes, and/or typical homes in Saudi Arabia. It provides about 30 m2 of roof space on which PV is installed. The generated energy will be used to contribute to the cooling system (air conditioning) energy needs and domestic hot water DWH.

5.3.3 House envelope design

Table 5.6 illustrates the final design of the housing envelope. In order for the U-values to be kept to a minimum, the external walls and the double skin insulating wall are designed with multiple layers and adequate thickness.

House Envelope	Construction Materials Used	Thicknesses	U-Value W/ m² k	R-Value m² k/ W
External Walls	Insulating Bricks, Polystyrene insulation, additional insulating Bricks, Dens EPS Slab Insulation and final insulating Bricks	40 cm	0.2021	4.7778
Roof	Clay Tile, fibre slab, sand, Vermiculite Aggregate concrete and Gypsum / Plaster Board - HF-E1 (ASHRAE)	45 cm	0.2126	4.4203
Floor	gravel- Based Soil, cast Concrete (DENSE), sand, Cork Tiles, Carpet and pad (ASHRAE)	67 cm	0.6244	1.1525
Internal partitions	Plaster, Brickworks and Plaster	13 cm	1.6896	0.3319
Ceilings	Cast Concrete (DENSE) and Synthetic Carpet	11 cm	2.28	0.2381
External Windows	Triple Glazing with cavities filled with argon gas		1.72 (Glass only)	

Table 5.6- Design Description of the House Envelop for House Prototype3

6 Simulation, Analysis and Validation

The three proposed house prototypes are assumed to be low energy structures, compared with current homes in Saudi Arabia. This assumption, however, must be tested and validated by comparing their energy consumption and CO_2 emission rates to those of current Saudi homes. These compared levels will be measured using international definitions for low energy housing systems expressed in kWh/m2. Each house design will be tested and simulated using IES-VE.

A BIM (Building Information Model) was created for each house prototype based on (a) architectural design, (b) selected construction materials, (c) on-site renewable energy techniques used, and (d) user profiles for an average Saudi family (Aldossary et al., 2014a, Aldossary et al., 2014b). The housing types will be compared to each other based on their area, energy consumption, and CO_2 emissions. This comparative analysis will outline the benefits and advantages of each house prototype.

6.1 Energy Consumption

It is important to mention that, Saudi Arabia characrise to have different hot climatic conditions hot arid climate, hot humid climate and hot arid mountainous region (see table 6.1). Each type of climate creates unique conditions that influence the energy requirements for cooling and heating. The energy consumption is known to be lower in the mountainous region than others regions; therefore, to attain realistic standards (in kWh/m^2) that can be applied countrywide, the measurements will be taken in one of the hottest most aggressive environment in Saudi Arabia and cold in wenter period, where the highest level of energy is require

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hot Arid Climate (Riyadh City)	**Max. Temperature**	28	31	37.8	39.6	44.5	45.6	46.8	46	45	38	30.4	27
	Min. Temperature	-5	-0.7	7	14	18.9	22.7	24.4	23	21.8	16.6	10.7	-1.2
	Relative humidity	44	25	13	19	15	9	10	12	16	26	49	34
Hot Humid Climate (Jeddah City)	**Max Temperature**	32	35	39	42	42	48	45	41.5	42	43	38	36.5
	Min Temperature	13	15.4	18	19	20	23.4	24.8	25	23.8	20	20	17
	Relative humidity	59	56	60	58	56	58	49	52	66	61	65	51
Hot Arid Climates with mountainous topography (AlBaha City)	**Max Temperature**	28.3	28.5	31.8	34	37	37	38	37	37.6	32	28.6	29
	Min Temperature	2.4	3	9	16	16	19	21	20	19.6	13	11	3
	Relative humidity	66	41	28	37	38	28	23	23	28	33	55	44

Table 6.1 Different Climatic Conditions in Saudi Arabia [54]

As expected, energy consumption for the three prototypes (based on IES-VE simulation results) is relatively low, but with different reduction levels. In this section, the energy consumption patterns for the three houses will be presented, in terms of: (a) annual energy consumption, (b) monthly energy consumption, (c) energy profiling (i.e. nature of consuming devices), (d) comparison of the energy consumption with international low energy housing definitions, and (e) annual CO_2 emissions rates. Moreover, the results will be compared to current energy consumption rates, as established in [21, 25].

6.1.1 Annual Energy Consumption

It is important to note that energy consumption will reflect the user profile of each room in the prototype. The average Saudi family comprises an average 6.2 individuals, according to the Central Department of Statistics and Information in Saudi Arabia. *The user profiles were investigated through interviews with the actual occupants [21, 25].* The usage of each room was individually established according to the duration and conditions of use (e.g. lighting, air-conditioning, equipment, and DHW). The final simulation will predict the annual energy consumption during prototype usage, taking into account the local climate of Riyadh City in Saudi Arabia. Figure 6.1 presents the total annual energy consumption in kWh for the three proposed low energy housing designs.

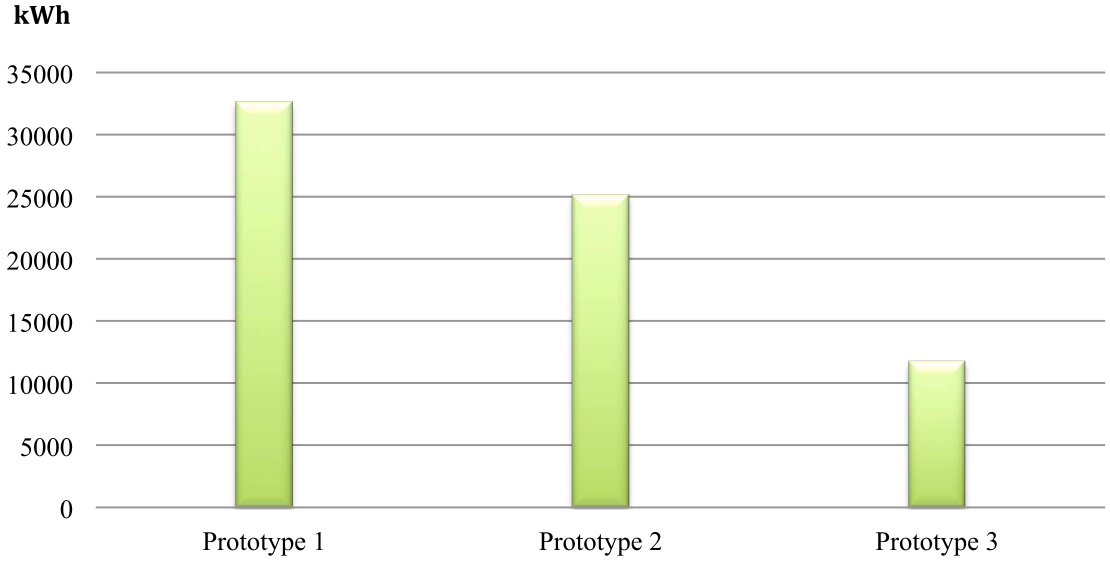


Fig 6.1- Annual Energy consumption for the three house prototypes (IES-VE simulation results)

These energy consumption levels are lower than existing homes in Saudi Arabia as established in [21, 25] where average energy consumption for a typical house in Saudi Arabia can be up to 60.000 kWh per year, depending on the type of climatic conditions (hot arid climate, hot humid climate, or hot arid mountainous conditions). The low level of energy consumption achieved reflects the final energy usage, including the energy predicted to be generated by each prototype. The IES-VE simulation tools have weather profiles for each capital city in the world, with the potential for each profile configuring the most important climatic conditions, including solar radiation. The three prototypes designed in this study have been simulated using the capital city of Saudi Arabia (i.e. Riyadh City), as it has the hottest and most arid climatic conditions in Saudi Arabia. Renewable energy technology has been suggested for all three prototypes. Saudi Arabia benefits from an abundance of solar energy, which can be utilised onsite in the form of renewable energy for domestic purposes. PV technology is flexible, and a popular choice for personal consumption, and hence has been used for each prototype in all three options, based on the roof area of each prototype. The output achieved from energy generation depends on the local availability of renewable energy. Saudi Arabia's climate is seen as a negative factor; however, it ensures access to large amounts of solar radiation. It has been established that onsite renewable energy systems can reduce energy consumption using renewable resources, rather than fossil fuels, in order to generate electricity [38, 39]. However, this practice largely depends upon the availability and location of adequate solar radiation to meet the occupants' annual demands. In the case study analysed, there are no renewable energy systems (e.g. PVs) in place to generate electricity and thus reduce CO_2 emissions. Rehman et al. (2007) [2] note that solar radiation in Riyadh city is approximately 1870 kWh/m^2 per year. Therefore, it can be stated that:

- Energy consumption of house prototype1 is up to 63% of the average energy consumption of similar existing homes, which represents a future potential reduction of 37%.
- Energy consumption of house prototype2 is up to 41.6% of an average similar house, representing a reduction of 58.4% in energy consumption, when compared with typical homes in Saudi Arabia.
- Prototype3 consumes only 28.3% of the energy consumed by a typical house in Saudi Arabia. Therefore, its construction would deliver up to a 71.7% reduction in energy consumption compared with similar homes in Saudi Arabia.

Fig 6.1 points out that house prototype3 has the highest performance in terms of low energy consumption due to its smaller size, efficient design form, and high quality fabric.

6.1.2 Monthly Energy Consumption

Fig 6.2 presents the monthly energy consumption levels for all three housing prototypes. Generally, these Houses require mechanical systems for cooling and energy consumption with a high demand during the summer months.

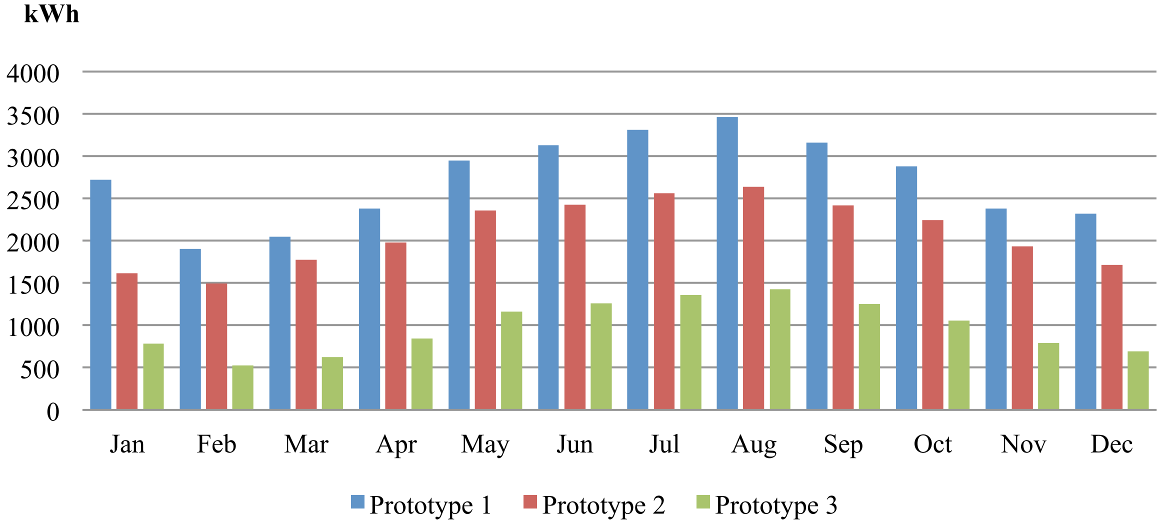
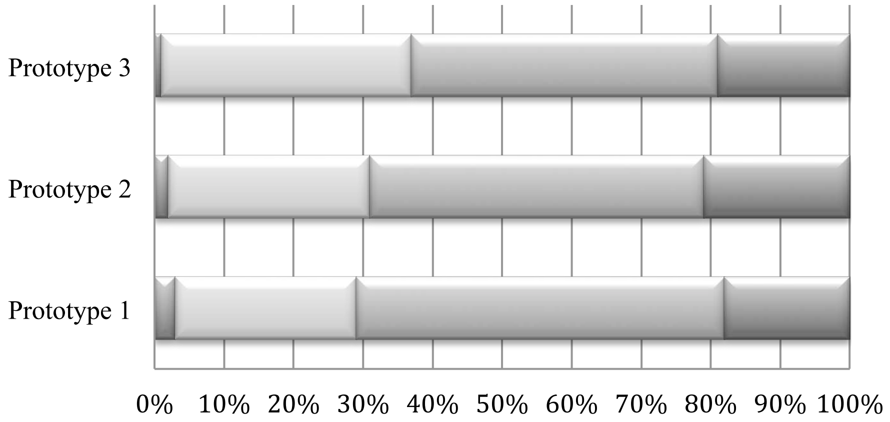


Fig 6.2- Monthly Energy Consumption for the three housing designs

6.1.3 Energy Consumption Profiling

As identified in previous studies [21, 25], the cooling system (air conditioning) accounts for the bulk of energy consumption (i.e. over 80%) in existing houses in Saudi Arabia. As mentioned previously, cooling systems in existing houses in Saudi Arabia usually consume about 70% and can sometimes consume over 80%. The IES-VE simulation results show that the percentage of energy used by the cooling system has been reduced and no longer presents a problem. Finally, the energy used for lighting, equipment or energy pumps, is not affected by the design of the form and fabric of the House. Form and fabric can affect energy use only for cooling or heating systems, in accordance with the local climate. Lighting energy can be reduced through the use of natural lighting and the efficient design of windows in each room, and by keeping the size and area of the windows to a minimum to prevent increasing the load on the cooling system. Energy profiling of each prototype is summarized in Figure 6.3.



	Prototype 1	Prototype 2	Prototype 3
▨ Heating system	3%	2%	1%
▨ cooling system (Chillers energy, Ap Sys heat rej fans/pumps energy)	26%	29%	36%
▨ Ap Sys aux + DHW/solar pumps energy	53%	48%	44%
▨ Lightings and Equipments	18%	21%	19%

Fig 6.3- Energy profiling for the three housing designs

6.2 Benchmarking Results with International Low Energy Houses Definitions

This section presents a scale from which to measure the level of low energy consumption for the three housing designs, as informed by official international low energy housing definitions and standards [19]. The housing design needs to focus on the cultural barriers, environmental responsibilities and availability of raw construction materials. The suggested standard for Saudi Arabia has been identified based on established design strategies for: (1) the climate of Saudi Arabia, and (2) cultural barriers [55]. As noted previously, there is a lack of any energy consumption standard for sustainable housing in the Middle East, as well as in the Gulf Cooperation Council (GCC) countries, with which to compare the results. Conversely, many developed countries have established a standard of energy use based on their needs and local climate conditions. Consequently, this study benchmarks the findings and the energy patterns for housing design according to these international low energy consumption standards. Figure 6.4 compares annual energy consumption in kWh/m2 for the three houses with a selection of international sustainable low energy standards.

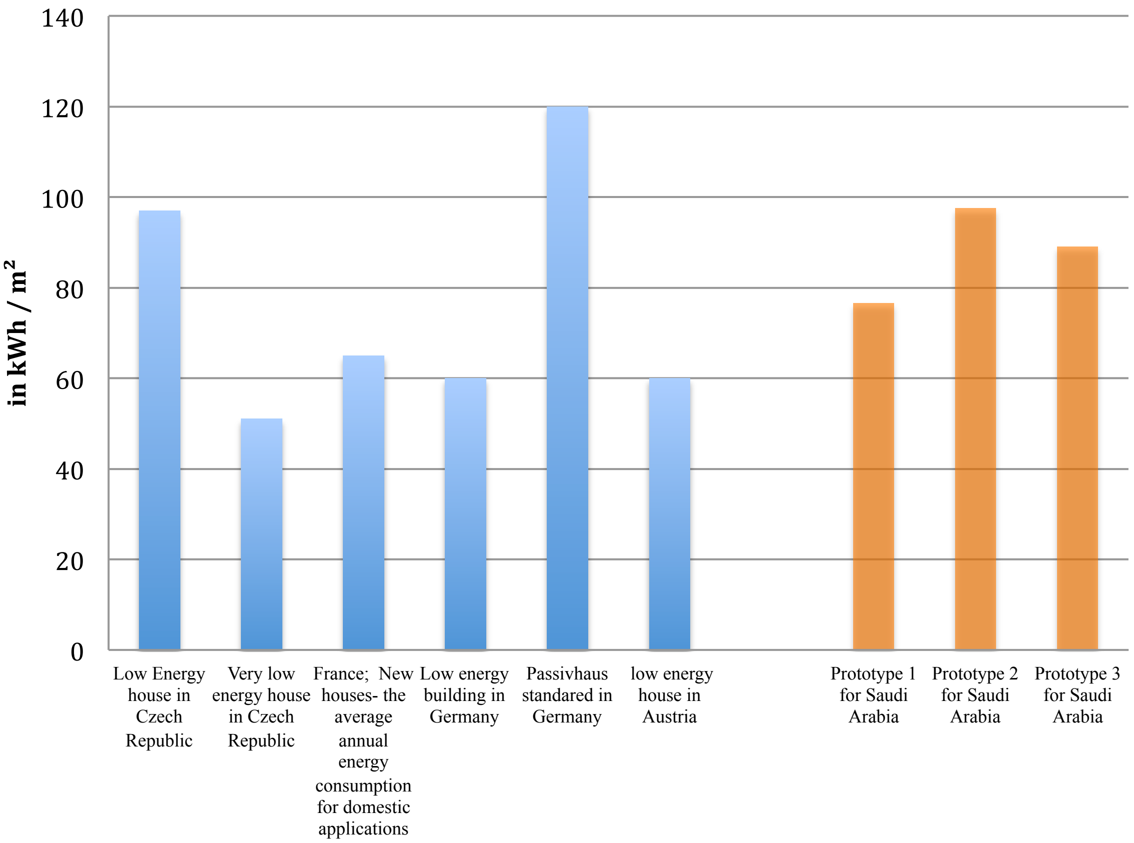


Fig 6.4- Benchmarking Energy Consumption in kWh / m2 with international standards

As illustrated in Figure 6.4, all three housing designs achieve lower energy consumption when compared with the low energy house in the Czech Republic and the Passivhaus standard in Germany. It is worth noting that other standards demand even lower energy consumption than achieved; i.e. the very low energy house in the Czech Republic or low energy House in Germany and France. Some other developed countries are still working to improve energy consumption and aim at achieving zero energy consumption by 2016; such as is the case for England and Wales in the UK.

6.3 CO_2 Emission Rates

Figure 6.5 illustrates annual CO_2 emission rates for each housing design. These rates range between 1700 and 6000 kg/year and as such are considerably lower than the CO_2 emission rates of typical existing homes in Saudi Arabia that reach up to 42570Kg/year [21, 25]. Clearly, these results represent a success in reducing CO_2 emissions and subsequently protecting the environment.

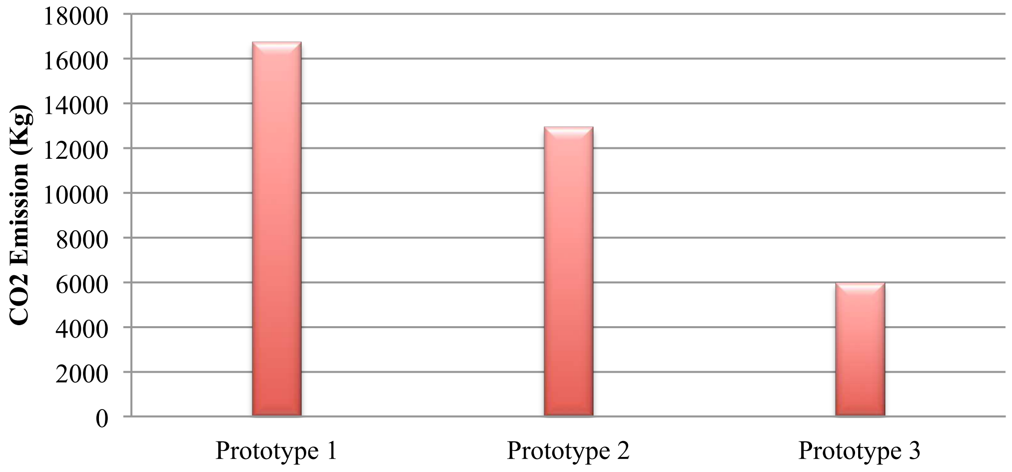


Fig 6.5- Annual CO_2 Emission rates (kg) for the three housing designs

According to Doukas et al (2006) [56], the average CO_2 emission rate per capita for the analyzed 25 European countries is about 2.5 tons per year. Thus, all three types of houses can be said to be close to, or lower than the average CO_2 emission rates per capita in these 25 EU countries. Figure 6.6 illustrates the annual CO_2 emission rates per capita, by dividing the total CO_2 emissions by the size of the average family (number of occupants) in Saudi Arabia. It can be seen that house prototype3 produces the lowest CO_2 emission rates, while house Prototype1 produces the highest. Yet in all three houses, both CO_2 emissions and energy consumption remain lower than rates in existing houses in the country.

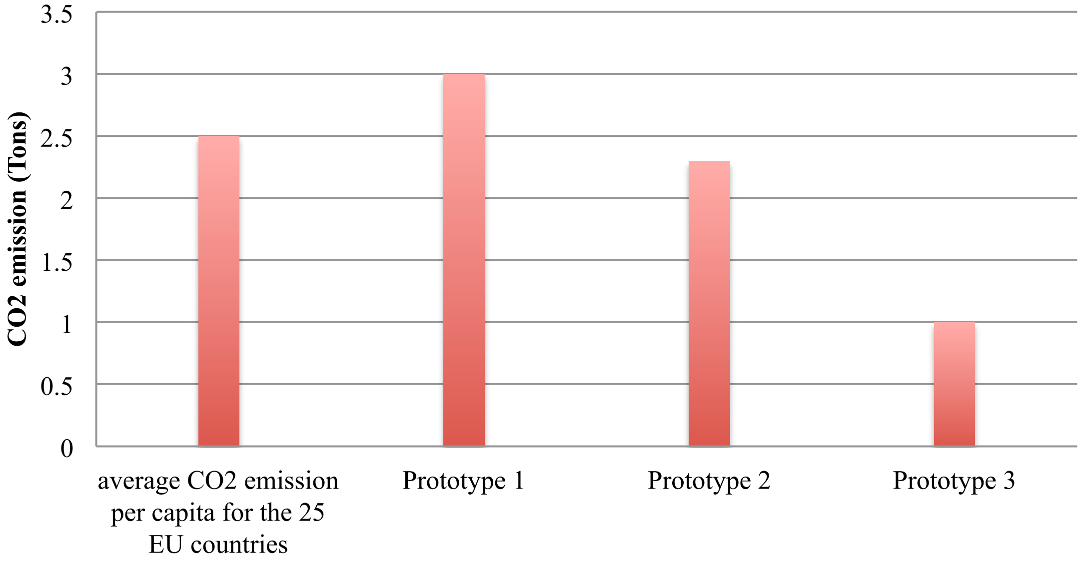


Fig 6.6- Annual CO_2 emission rates (per capita) for the three housing designs compared with 25 EU Countries

7 Low Energy Consumption Definition Standard for Saudi Arabia

This section focuses on the establishment of a low carbon energy consumption reference for Saudi Arabia that factors in climate and socio-cultural constraints. The economic and environmental benefits of the adoption of such a reference system are discussed.

The Saudi government subsidizes energy use in the residential sector. Moreover, occupants do not pay for actual energy consumption as the cost of consumed energy is subsidized [57]. The electricity bills of the population are already subsided by the government. Occupants not pay less than the original cost of subsidised electricity [57]. Ideally, the Saudi government should regulate energy prices based on predicted annual energy use, balancing supply and demand, as is the case in Western countries.

Ideally, the Saudi government should regulate energy price based on predicted annual energy use, balancing demand and offer, as is the case in western countries. According to the Ministry of Municipality in Saudi Arabia, planning consent is granted if the following requirements are met:

(a) The area should not be more than 60% of the site area allocated in the deed.

(b) The distance between the House periphery and the property line should not be less than 2m, to maintain the privacy.

(c) Only two floors should be completed, and no more than 25% of the roof should be built.

(d) The distance between the main elevation of the House and the street should not be less than 4m.

(e) The distance between the side entrance (if allocated) and the boundary / property line should not be less than 3m.

(f) Some other general requirements related to the property approval.

Outward appearance and privacy are the determining factors for home design in Saudi Arabia. There is no incentive or planning requirements to encourage / force engineering consultants to design low energy houses, and there is no related building energy legislation in place. The Energy Performance Building Directive (Directive 2002/91/EC) introduced the compulsory energy certification of buildings in the EU. This is now a key reference to monitor and reduce energy consumption in the European building stock. A similar directive should be enforced in Saudi Arabia and the wider region requiring a domestic energy performance between 77 kWh/m2 and 98 kWh/m2, as established in this study. Moreover, this should be enforced at planning stage. These measures will have a real impact on the domestic sector which currently accounts for over 50% of the energy use in Saudi Arabia.

According to the report of the Ministry of Electricity, the sold energy for the housing sector in 2010 was 108,627 GWH [58]. Hence, energy savings between 40% and 75% can be achieved through the application of the established framework for sustainable homes in Saudi Arabia, alongside the application of the three prototypes. Figure 7.1 illustrates the benefits of each of the houses designed in this study.

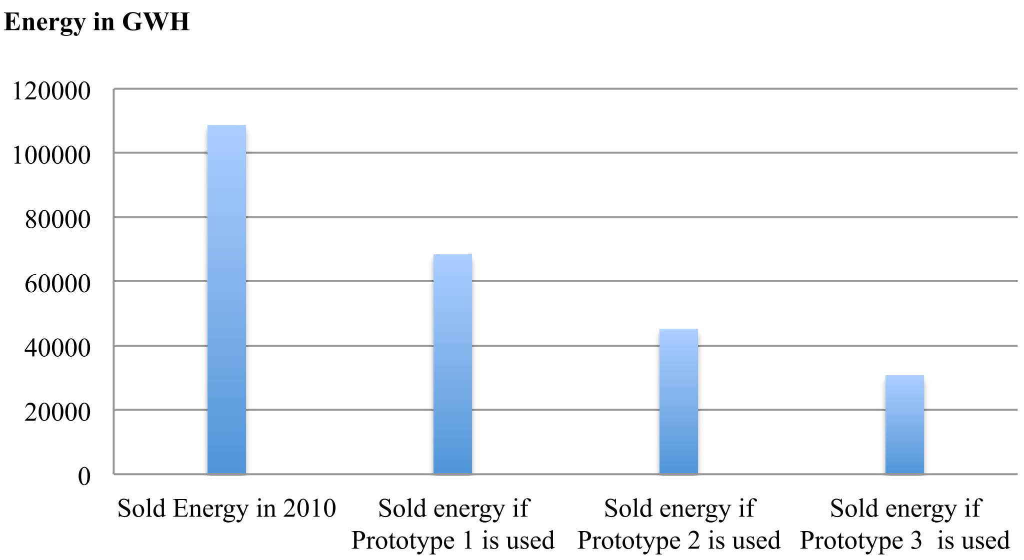


Fig 7.1- Prediction Energy Saving Strategically through implementing these houses in Saudi Arabia

The housing sector in Saudi Arabia consumes over 50% of energy in comparison with the other sectors. This energy needs to be effectively conserved and managed by the Ministry of Municipality. A number of factors have the potential to contribute to energy saving, including: (1) efficient design of building fabric; (2) architectural design; (3) the application of on-site renewable energy; and (4) public awareness. Designs will vary according to the requirements of both climate and budget. Moreover, the result will further vary in response to the final design of the project. Hence, energy can be managed by establishing an energy consumption standard definition in kWh/m2, as experienced in other developed countries. Saudi Arabia will need to establish its own definition standard, based on local climate conditions, along with the culture and behaviours of the occupants.

According to the ministry of housing, there is a rising demand for housing over the next 10 years [59]. The demands for future housing will require the erection of 214,433 residential units [59]. This figure reflects a serious challenge and illustrates the importance of designing low energy homes in the future. Moreover, this figure reflects the potential scale and benefits that could be achieved by implementing low carbon interventions.

According to [60], recent successes in adopting on-site renewables can be attributed to public financial incentives. Adapting the energy industry to allow more efficient and sustainable electricity production increases the importance of distributed generation from renewable sources (e.g. PV) [61]. Incentivising and implementing proposed solutions for existing houses and flats across Saudi Arabia will require complementary measures to be put in place. Policies could be developed and enforced to encourage home owners to retrofit their dwellings. A dramatic reduction in energy use will not only save on the cost of electricity, but will also significantly reduce the amount of CO_2 emissions and will enhance the international profile of the country with significant social, economic and environmental benefits [62].

8 Conclusion

The paper has applied a framework of designing sustainable low energy housing in Saudi Arabia. Three prototypes were suggested for low energy houses, all of which have factored in the Saudi Arabian climate, culture and the needs of occupants. The three prototypes differ in terms of area, along with the envelope of individual buildings, and architectural design strategies. The energy performance of these prototypes has been validated using the IES-VE energy simulation environment to establish the extent of energy reduction in comparison with current homes. Based on this analysis, there is a proposal for low carbon energy consumption targets for Saudi Arabia, ranging between 77 kWh/m2 and 98 kWh/m2. This level of energy consumption compares favourably with international definitions of energy consumption in Germany, the Czech Republic and France. There has also been a discussion of the economic and environmental benefits of the adoption of such a reference system, and a number of recommendations informed by this study can be formulated.

- Design codes should be developed to assist designers to achieve the definition standards.
- Saudi Arabian building regulations should be reformed to promote, and enforce, the delivery of low carbon homes, including energy retrofitting the existing domestic stock

- Framework design strategies [55] should be employed in the construction industry, in order to design future sustainable low energy housing.
- The Saudi planning consent process should be revised to include energy performance requirements, in line with findings of this study.
- The Saudi government should revise its energy policy to promote and incentivise the adoption of clean energy, i.e. solar energy.
- Occupants should be encouraged to design their homes to have low energy consumption by a limit being placed on the amount of energy subsided, with the remainder being maintained at the original price.
- Graduating architects and engineers need to be trained in sustainable design, focused on the culture and climate of the Middle East.
- The curriculum in construction and built environment faculties concerning the built environment should be revised, to address issues of low energy design, in order to engage with the international trend.

Acknowledgments

This study is commissioned by the Saudi government and it is hoped that it will pave the way to a cleaner energy landscape in the region.

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