Towards Sustainable Residential Buildings in the Kingdom of Saudi Arabia

Hanan M. Taleb
Ph.D. Researcher
University of Sheffield, UK
Email: Arch.Hanan.Taleb@Gmail.com

Abstract
This paper assesses the energy and water use practices of existing residential buildings in Saudi Arabia, with the ultimate aim of establishing guidelines for delivering sustainable architecture in the near future. In order to achieve this overall aim, the current status of a typical Saudi residence is thoroughly investigated, in terms of energy and water consumption, using simulation software packages. The paper then examines the prospects for applying various means to manage energy and consumption more sustainably. In essence, this research identifies several design-related faults common to Saudi Arabian house design. These faults contribute to an inefficient use of energy and domestic water resources. Finally, the paper puts forward a set of recommendations and guidelines, design-related and otherwise, in order to enhance the sustainability level of Saudi residential buildings.

1. Introduction

With the growing evidence that the phenomenon of climate change is caused by greenhouse gas emissions, it has become necessary to take immediate action to avoid dangerous consequences for future generations. Due to a rapidly escalating population and a high level of economic growth, the Kingdom of Saudi Arabia is a country that is experiencing a vigorous infrastructure expansion, especially with respect to residential buildings. Unfortunately however, when compared to other countries, the issue of energy efficiency is not being taken into serious consideration with regard to Saudi building designs. Moreover, the Kingdom of Saudi Arabia is recognised as one of the driest regions in the world and it is facing serious challenges related to a rapid growth in water demand compounded by arid climatic conditions. In this regard, the authors believe that sustainable architecture should be actively pursued with a sense of urgency in Saudi Arabia. In order to achieve this goal, efforts should be made by Saudi architects to minimise buildings' water and energy use and to encourage energy efficiency through the use of climate responsive designs as well as environmentally-friendly renewable energy technologies.

Firstly, the paper provides a brief overview of the current status of the Saudi building sector in terms of sustainability. Following this, the paper presents the flat complex that was selected as a case study for the purpose of this research. An assessment of energy and water use within this building is then provided, followed by suggested modifications along with their potential improvements. Finally, several recommendations in order to enhance the sustainability level within the Saudi residential sector are provided.

2. Sustainability Status in the Saudi Building Sector

Generally speaking, sustainability encompasses a blend of environmental, economic and social responsibilities. Given recent environmental and energy concerns, there has been a considerable interest in recent years with regard to the concept of sustainable architecture. The main drivers behind promoting sustainable architecture are definitely ecological and energy considerations, as well as some other factors such as health-related concerns and the desire to improve the residents' quality of life (Edwards, 2005). In principle, sustainable buildings relate to the notion of climate-responsive design, which places emphasis upon natural energy sources with the aim of achieving building comfort through the interaction with the dynamic conditions of the building environment (Hyde, 2000). For example, the placement of windows in a sustainable building is of greatest importance, as it should provide effective natural light and ventilation.

Such principles are obviously absent in current Saudi buildings, which are heavily dependent on air conditioning that consumes massive amounts of electricity. Apparently, as a result of poorly designed buildings in Gulf Cooperation Council (GCC) countries, nearly 80% of household electricity is used for air conditioning and refrigeration purposes (Akbari et al., 1996). In Saudi Arabia, as a result of a rapid population growth and increased urbanisation, not only is the residential sector booming, but it also constitutes more than half of the country's energy demand (Al-Shehri, 2008). Moreover, it is unfortunate to note that electricity generation in Saudi Arabia is completely dependent on the unsustainable practice of burning fossil fuels, which causes major environmental consequences that include an impact on air, climate, water and land (Alnatheer, 2006). In addition, despite the abundant availability of renewable energy sources, the use of sustainable energy technologies, such as solar photovoltaics (PV), is exceptionally rare in the oil-rich Saudi Arabia (Al-Saleh et al., 2008, Taleb and Pitts, 2009).

With regard to the water issue, Saudi Arabia is considered to be one of the driest regions in the world. It has no permanent rivers or lakes and the country depends heavily on water desalination plants to bring water supplies to the population scattered across the large Kingdom. The government has been tackling the issue of increasing water demand, which is manifest in the domestic sector, by the development of 33 desalination plants, thereby making Saudi Arabia the world's largest producer of desalinated water (Vincent, 2008). In spite of the limited availability of natural water resources in Saudi Arabia, its water tariffs – due to high subsidies provided by the government – are set at approximately $0.03/m^3, compared with over $6/m^3 in many wet regions around the world (Gasson, 2008).

Such an artificially low price for water, as well as for electricity, provides no incentive for water and energy conservation; hence the design of Saudi houses tends to lay stress on a luxurious style of living without paying attention to sustainability principles. For instance, when compared to the rest of the world, Saudi houses tend to be relatively large residences with spacious toilets and air conditioning units running around the clock. Therefore, there is a pressing need to improve the efficiency of energy use and water consumption in Saudi buildings through the application of sustainable architectural principles. Recent studies indicate that having abundant oil reserves, heavily subsided electricity and water prices, a lack of awareness with regard to environmental concerns as well as a lack of regulations and policies in terms of sustainable construction implementation, are among the most significant barriers to a thriving sustainable architecture in Saudi Arabia (Al-Yami and Price 2005). Nonetheless, some of the developments and initiatives recently taken by the government are indeed steps in the right direction. For example, although progress in the field of wastewater treatment has thus far been very slow, it is expected to receive more attention in the country following the recent establishment of the National Water Company (Fallatah, 2008). Moreover, according to AlZahrani et al. (2007), the government has already implemented a number of campaigns in order to increase people's awareness of the problem of water scarcity and the importance of its conservation in Saudi Arabia. It is hoped that this study will contribute to such a tentative, yet promising, move towards the move to sustainable housing in the country.

3. The Case Study: An Introduction

A typical residential building (i.e. a flat complex) was selected to act as a case study for this research. This residential building is situated in Jeddah City, which is a diverse and rapidly growing commercial city, located on the Red Sea (21° 30' N and 39° 10' E), that is considered to be an important gateway to the Islamic holy cities of Makkah and Madinah. When conducting an analysis on the energy use and/or water consumption of the building, it is useful to consider the climatic conditions that affect it. The climate in Jeddah during the summer is characterised by fierce heat and high humidity, which tends to be unbearable towards the end of the summer season. During winter, it maintains its warmth, but with reduced humidity with some rain occasionally falling in November and December in small amounts (Ham et al., 2004). Detailed information on temperatures and the rather high solar radiation levels in Jeddah throughout the year are given in Figure 1.

The recently-built residential building that has been chosen is located in a relatively new district, most of which has been witnessing heavy construction activity in recent years. The building comprises of three stories and six flats, with a floor built area of 420 m^2 and a total land area of 625 m^2. Figure 2 illustrates the floor plans and elevations of the case study. Each of the six two-bedroom flats is occupied by three residents, and is assigned a car parking space in front of the building. This flat complex represents a typical residential building in Saudi Arabia. According to statistics provided by the Saudi Ministry of Economy and Planning (2005), flats similar to this, are the most common type of residence in Saudi Arabia.

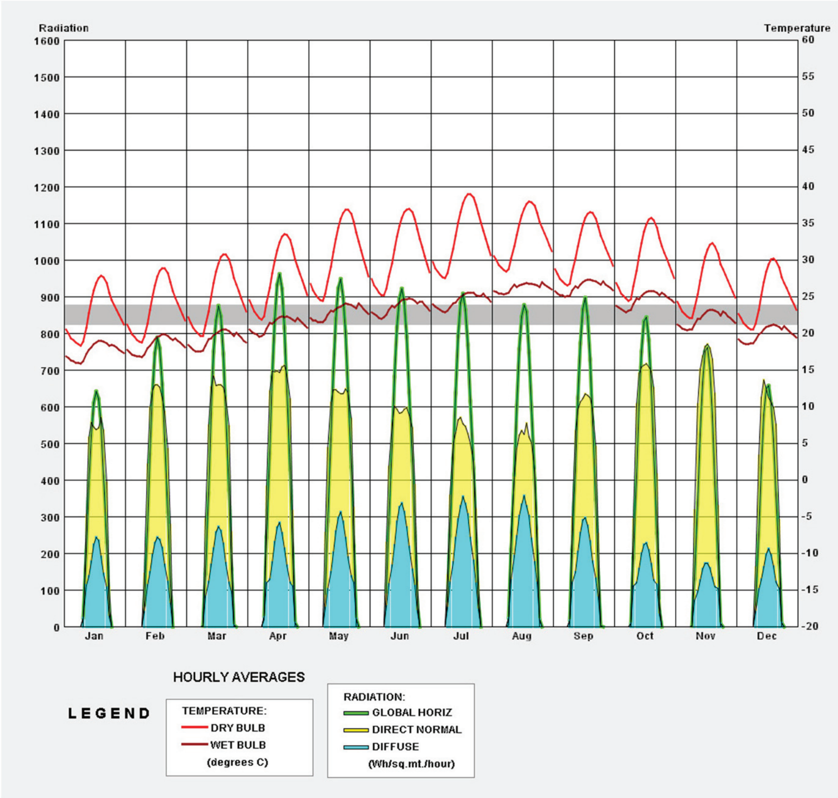

Figure (1): Temperature and Solar Radiation Levels in Jeddah
(Source: Climate Consultant 4 Software)

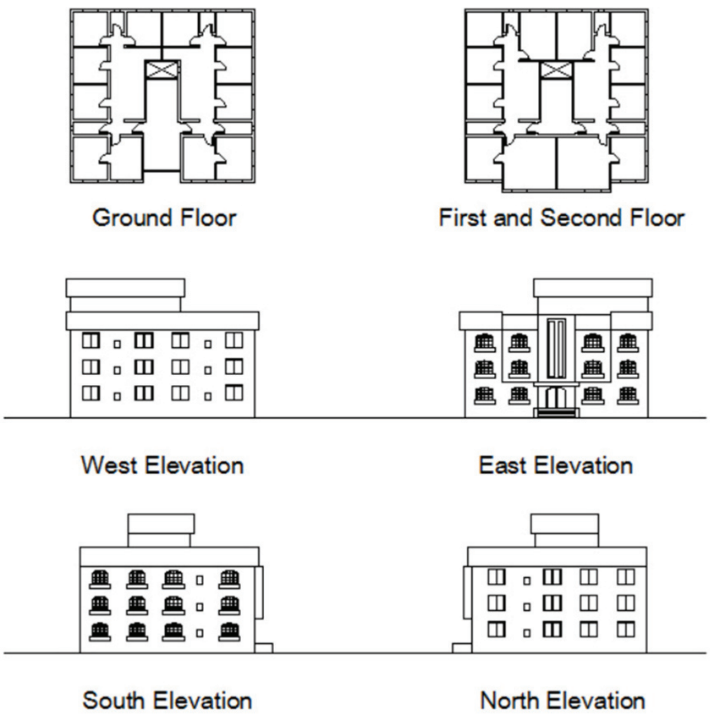

Figure (2): Floor Plans and Elevations of the Residential Case Study

4. Analysing the Case Study

4.1. Energy Use

The energy use within the flat complex was analysed using Design-Builder, which is based on the state-of-the-art building performance simulation software entitled EnergyPlus. In essence, Design-Builder is a commercially available software package that provides a dynamic and comprehensive energy simulation for buildings. A three-dimensional (3D) model for the case study was firstly developed based on the building's drawings, and after conducting a site visit and intensive consultation with the complex owner, who oversaw the construction of this building himself. The calculation results for the energy use

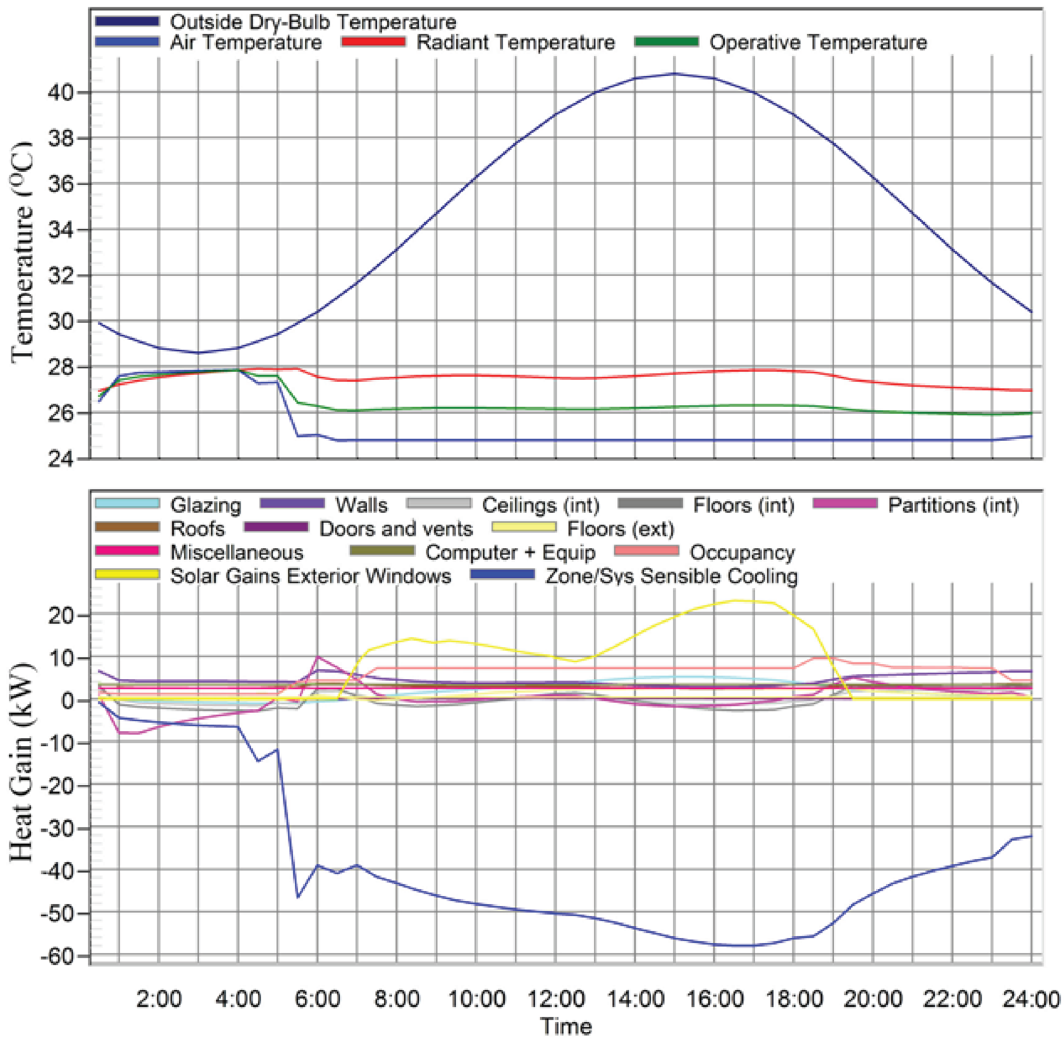

Figure (3): Temperature and Heat Balance of the Building on 15 July

simulation at the building level on one of the typical summer days of the year in Jeddah (i.e. 15 July) are plotted as a graph in Figure 3. This graph shows temperatures (in ^{o}C) at the top, with all actual heat balances (in kW) at the bottom. The temperatures shown are the outside temperature (in dark blue), air temperature (blue), radiant temperature (red) and finally (in green) the ‘operative or comfort temperature’ which is the average of the last two. Whilst the temperatures shown are averaged from across all the building, the heat balance (i.e. gains and losses) are totalled across the whole building depending upon its structure and climatic conditions. For instance, the graph shows the direct solar gain through windows (in yellow) being highest during the late afternoon.

The energy use within the building was examined throughout longer timeframes, e.g. weeks, months and seasons. Next, the energy use within the building was simulated for a whole year, using real climatic data. According to the simulation results, the annual electricity consumption for the building was 146,372 kWh, which also implies the emission of approximately 101 tonnes of CO_2 per year. The annual electricity consumption per flat was then obtained by dividing the annual consumption for the building by the number of flats (i.e. 6). Hence, the average annual per capita figure for each flat is estimated at around 24,386 kWh, which may seem exceptionally high when compared with other parts of the world with similar climatic conditions. An attempt was therefore made to validate such a high calculated electricity use rate. Eventually, not only did it show reasonable agreement with readings obtained from actual utility bills, but the estimate seemed to be a conservative one when bearing in mind that typical household electricity consumption for a Saudi flat was reported to be 20,000 kWh per year more than a decade ago (Al-Ajlan et al., 1998). No more recent published estimates for typical electricity use for 2-bedroom flats in Saudi Arabia seem to be available in the literature.

4.2. Water Consumption

Understanding the current water consumption is the first step in improving water efficiency within the building. The estimation of water use in the case study is largely based on an adapted version of BRE Code Water Calculator, which is used within the Code for Sustainable Homes assessment methodology. After undertaking necessary training and examinations in the United Kingdom, the author has become a licensed Assessor for the BRE Code for Sustainable Homes, and hence formally qualified to use this software-based calculator. Based on the number and type of fittings and appliances installed in a house, this calculator determines the average water consumption per capita, using typical usage patterns for each user. The following table (table 1) contains the input figures which were assumed for the purpose of this exercise. These assumptions were based on the manufacturers' specifications (for items) and real experiments (for additional activities that were not originally considered by the software package).

Table (1): Assumed Input Data for Water Consumption Analysis

ITEM	2x Basin taps	Flow rate: 10 Litres/min
	Fixed-flush cistern	Capacity: 8L
	Bidet	Consumption: 2.64 L/use
	Shower	Flow rate: 18 Litres/min
	Bath	Capacity to overflow: 225L
	2x Kitchen sink taps	Flow rate: 15 Litres/min
	Washing machine	Consumption: 151 L/cycle
ACTIVITY	Ablution	Consumption: 26 LCD (Litres per capita per day)
	Toilet cleaning	Consumption: 21 L/toilet per day (i.e. 14 LCD)
	Car washing	Consumption: 126 L/car per week (i.e. 6 LCD)
	Irrigation/courtyard cleaning	Consumption: 252 L/building per week (i.e. 2 LCD)
		Total: 498 LCD

Having modelled and assessed the water consumption for the case study, the average daily amount of water consumed was estimated as being 498 LCD. An attempt was then made to validate this rough estimate. To do this, last year's water utility bills were collected and studied, whilst bearing in mind the number of times private water trucks that had to be procured over the last year. According to the collected water bills, the consumption rate over the last year averaged around 560 LCD; i.e. 62 LCD higher than the calculated consumption rate. This finding seems logical given that the calculated figure did not take into account any potential losses in the system due to leaks. Further attempts were also made to compare the calculated per capita figure of 498 LCD with published estimates in the literature. Apparently, this figure is higher than the anticipated rate of 435 LCD that was forecast a couple of decades ago by Abdulrazzak and Khan (1990). Given that it is comparable to recently reported rates within other GCC countries (e.g. Alshawaf, 2008; Darwish et al., 2008; Sorenson, 2007), it could be suggested that the estimated consumption rate of 498 LCD represents an average Saudi household water consumption rate. This rate would indeed place it among the highest in the world, bearing in mind that the European average is approximately 200 LCD, whereas in many places in

Africa it is much lower than 20 LCD (UNDP, 2006).

5. Rendering the Case Study More Sustainable

5.1. Energy Use

If the building was still at the design stage, a number of measures could have been taken in order to enhance the energy efficiency and hence reduce the electricity consumption of the building. Some of the available options include: insulating external walls and the roof of the building, using fluorescent lights instead of the less-efficient incandescent lamps (say 70% of building's lighting could be of the fluorescent type), using double-glazed windows and fitting shading devices (e.g. windows with side fins and overhangs). A range of other energy-efficient practices indeed exist around the world, e.g. fitting lighting controls in order to control the light according to the daylight luminance. Nonetheless, re-running the Design-Builder simulations with the above few modifications shows a significant improvement in terms of energy efficiency. Having made these few changes to the model input data, Figure 4 shows the energy simulation results for 15 July in order to compare the potential improvement as a result of such modifications. Obviously, the solar gain (in yellow) has been reduced when compared to the original design. This is largely attributable to fitting shading devices on the windows, which are, in turn, of the double-glazing type.

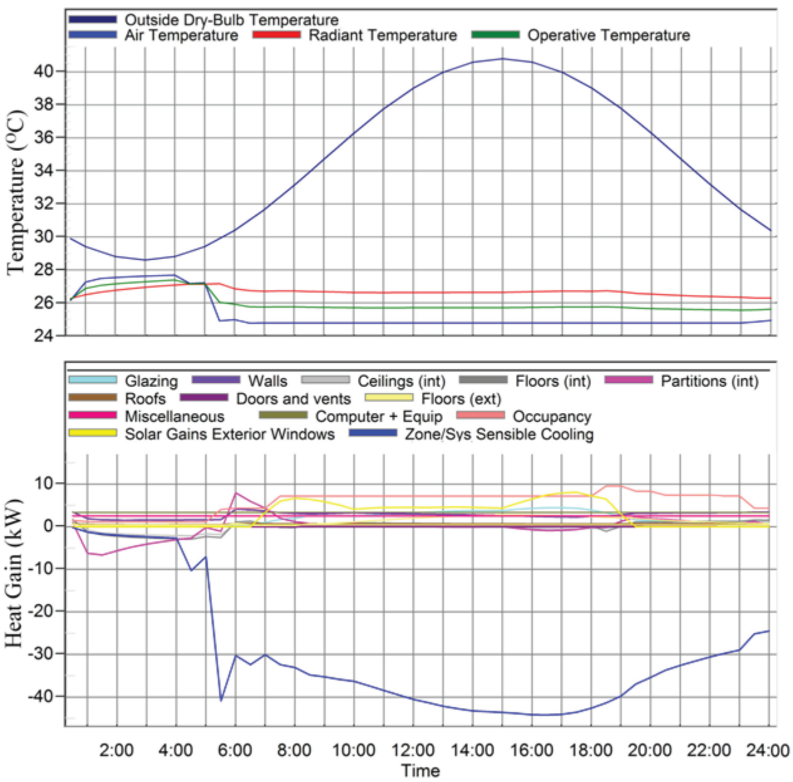

Figure (4): Temperature and Heat Balance of the Building – after modifications – on 15 July

The calculated annual electricity use and resulting CO_2 emissions for the whole building was estimated to be around 98,992 kWh and 69 tonnes respectively. This translates into a possible 32.4% reduction in annual household electricity consumption as well as 32 tonnes of potential saved CO_2 emissions. In fact, if all the flat complexes in Saudi Arabia (i.e. over 300,000 buildings based on data provided by the Saudi Ministry of Economy and Planning, 2005) had managed to achieve such an attainable level of energy savings, at least 10 million tonnes of CO_2 could be saved per annum within the Saudi residential sector. A further modification that could be made to the case study is the incorporation of renewable energy technologies. Given the high level of solar irradiation in Jeddah as well as the available free space area on the roof of the building, solar PV panels could be fitted in order to supply around 10% of the household electricity requirements. Consequently, the amount of household CO_2 emissions could be reduced by another seven tonnes per year (see Figure 5). Given the current high capital cost however, the use of renewable energy options within the Saudi residential sector might not be viable at present. However, their viability could be significantly boosted if the government lifts the heavy cost subsidies for fossil-fuel electricity generation, whilst setting a range of financial incentives, such as net metering, feed-in tariffs and capital cost subsidies for renewables (Al-Saleh et al., 2008).

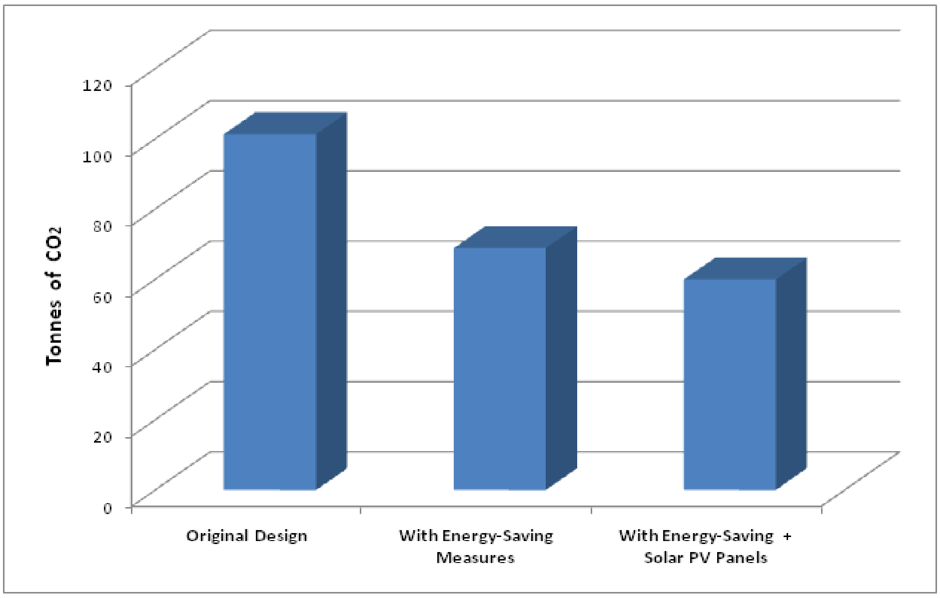

Figure (5): Potential CO_2 Emission Reductions for the Case Study

5.2. Water Consumption

Apparently, there are many different ways to reduce such high domestic water consumption within Saudi residential buildings. The following table (table 2) suggests only a few 'moderate' modifications to the flat complex, along with their water saving potential. These potential water savings were estimated using the BRE Code Water Calculator. It should be noted here that much of the water-efficient items listed below, with perhaps the exception of the last one, are considered pretty much as being the normal practice in developed countries.

Table (2): Suggested Water-saving Devices

Modification	Potential Saving (in LCD)
Low-flow tap aerators in the kitchen (9 Litres/min)	63.5
Low-flow tap aerators in the bathroom (6 Litres/min)	42.3
Low-flow showerheads (9 Litres/min)	27.0
Dual-flush (6/4 Litres) cisterns	16.0
Efficient washing machines (49 Litres/min)	34.7
A grey-water system, which collects 90% of the bath and shower waste in order to supply toilet cisterns	38.4

According to the above table, a total water savings of 222 LCD could be achieved if all of these modifications were carried out. This outstanding saving means that 3,996 litres could be saved in a day, or over 1,458,000 litres a year from this single flat complex alone. Indeed, there is a range of other ways to further reduce water consumption, some of which require a sensible use of water. Examples of sensible behavioural changes include reducing shower times and turning off the taps when brushing teeth or shaving. Moreover, instead of using a running hose to wash a car, a trigger hose or even a bucket with a sponge should be used. The house occupants admitted that they never thought about, or rather felt the need to think about, ways to conserve domestic water. It is important to recognise here that the rational use of water and other natural resources is embedded within Islamic principles (e.g. see Faruqui et al., 2000). Finally, an example of design-related improvement that could be applied in new houses is the use of shading devices in order to reduce the water requirement of plants.

6. Guidelines for a Sustainable Future within the Saudi Residential Sector

From the above case study analysis, the following is a list of summarised guidelines that would help achieve sustainable architecture, in terms of energy and water use, within the Saudi residential sector:

- To follow the principles of climate-responsive design when designing houses in order to improve the energy performance of residential buildings.

- To use sufficient insulation in walls on roofs.
- To place windows in such a way as to maximise the utilisation of natural light and thereby lessens the need for electric light during the day. Windows should also be opened during winter in order to allow for natural ventilation and reduce the demand for mechanical air conditioning.
- To use appropriate shading systems in order to properly shade residential buildings and their gardens from excessive solar radiation.
- To integrate zero-carbon energy technologies such as solar PV and/or wind turbines if feasible.
- To use energy-efficient lighting and electrical equipment.
- To make use of water-saving means, such as low consumption sanitary fittings and controls as well as using grey water recycling in Saudi building designs.

In addition to the above design-related recommendations, the following are general, yet relevant, guidelines which could also contribute towards achieving sustainability in Saudi Arabia:

- To allocate secure and suitable storage spaces for bikes, and encourage tenants to use them for short journeys instead of the utter reliance on private cars.
- To promote household waste recycling schemes, which currently do not exist.
- At the building design stage, only recycled and responsibly sourced construction materials should be selected.
- To launch intensive electric and water rationing schemes.
- To initiate public awareness programmes on the need for conserving natural resources and the importance of recycling.
- To impose strict plumbing codes and penalties for wasting household water, as well as removing the consumer price subsidies on conventional fossil-based electricity.
- To encourage the use of energy and water efficient household appliances, whose prices could be subsidised by the government.
- To introduce and enforce sustainability assessment systems, which are tailor-made to assess Saudi homes in a two stage process (i.e. design stage and post-construction).
- To allocate the necessary resources to enhance awareness with regard to sustainable architecture among architects, engineers and the general public.

7. Concluding Remarks

Around the world, especially in sustainability pioneering countries, reducing household energy and water consumption makes a lot of economic sense.

One could argue that it is the economic incentive, along other factors such are enhanced public awareness, which could determine the successful adoption of sustainability measures in Saudi houses. It is therefore recommended that the heavy consumer subsidies on the current price of electricity and water should be removed in order to rationalise energy and water consumption within the Saudi residential sector. This study, which has examined in detail a typical Saudi residential building (i.e. flat complex), does not only show that such a building severely lacks the means to ensure energy and water efficiency, but it also demonstrates how a few changes could have a significant impact on the sustainability performance of the building. Having identified many shortcomings common to the current design of Saudi houses, this paper puts forward a number of strategies which should help towards the development of a sustainable residential sector in Saudi Arabia.

8. References

Abdulrazzak, Mohammed and Khan, Muhammad (1990) "*Domestic Water Conservation Potential in Saudi Arabia"*, Environmental Management. Vol. 14, No.2, pp. 167-178.

Al-Ajlan, Saleh, Mohamed Smiai and Elani, Ussama (1998) "*Effective Tools Toward Electrical Conservation in Saudi Arabia"*, Energy Conservation and Management. Vol. 39, No.13, pp. 1337-1349.

Al-Saleh, Yasser, Paul Upham and Malik, Khaleel (2008) "*Renewable Energy Scenarios for the Kingdom of Saudi Arabia"*. Tyndall Centre for Climate Change Research, Working Paper 125. Available from: http://www.tyndall.ac.uk/publications/working_papers/twp125.pdf [accessed 30 October 2008].

Alshawaf, Mohammad (2008). "*Evaluating the Economic and Environmental Impacts of Water Subsidies in Kuwait*", Unpublished M.Sc. Thesis: Louisiana State University.

Al-Shehri, Abdullah (2008) "*Electricity Industry in Saudi Arabia: An Overview"*, In Saudi Water and Power Forum, Jeddah, 1-4 November 2008.

Alnatheer, Othman (2006) "*Environmental Benefits of Energy Efficiency and Renewable Energy in Saudi Arabia's Electric Sector"*, Energy Policy. Vol. 34, No.1, pp. 2-10.

Al-Yami, Ali and Price, Andrew (2006) "*An Overview of Sustainability in Saudi Arabia"*, In The Joint International Conference on Construction, Culture, Innovation and Management. Dubai, 26-29 November 2006.

Alzahrani, Khordan, Imad Elsahfie and Muneer, Siddig (2007) "*Factors Affecting Adoption of Water Conservation Practices in the Household Sector in Riyadh, Saudi Arabia"*, In World Water Week. Stockholm, 12-18 August 2007.

Akbari, Hashim, Muhammad Morsy and Al-Baharna, Naser (1996) “*Electricity Saving Potentials in the Residential Sector of Bahrain”*, Berkeley: Lawrence Berkeley National Laboratory.

Darwish, Mohammad, Fatimah Al-Awadhi, and Darwish, Ahmed (2008) “*Energy and Water in Kuwait Part I: A Sustainability Overview”*, Desalination. Vol. 225, No.1-3, pp. 341-355.

Edwards, Brian (2005) “*Rough Guide to Sustainability”*, London: RIBA Enterprises Ltd.

Fallatah, Mahmoud (2008) “*Business Opportunities in Water and Wastewater Sector in Saudi Arabia”*, In Saudi Water and Power Forum. Jeddah, 1-4 November 2008.

Faruqui, Naser, Asit Biswas and Bino, Murad (2000) “*Water Management in Islam”*, Tokyo: United Nations University Press.

Gasson, Christopher (2008) “*Tariff Policy: A Global Perspective”*, In Saudi Water and Power Forum. Jeddah, 1-4 November 2008.

Ham, Anthony, Martha Shams and Madden, Andrew (2004) “*Saudi Arabia”*, London: Lonely Planet Publications.

Hyde, Richard (2000) “*Climate Responsive Design: A Study of Buildings in Moderate and Hot Humid Climates”*, London : E. & F. N. Spon

Saudi Ministry of Economy and Planning (2005) “*Estimating the Demand for Housing in the Kingdom of Saudi Arabia over the Period 2005-2025”*. Available from: http://www.planning.gov.sa [accessed 17 August 2008].

Sorenson, David (2007) “*An Introduction to the Middle East”*, Boulder: Westview Press.

Taleb, Hanan and Pitts, Adrian (2009) “*The Potential to Exploit Use of Building-integrated Photovoltaics in Countries of the Gulf Cooperation Council”*, Renewable Energy. Vol. 34, No.4, pp. 1092-1099.

United Nations Development Programme ‘UNDP’ (2006) “*Human Development Report: Beyond Scarcity: Power, Poverty and the Global Water Crisis”*, Basingstoke: Palgrave Macmillan.

Vincent, Peter (2008) “*Saudi Arabia: An Environmental Overview”*, London: Taylor & Francis.

نحو مباني سكنية مستدامة في المملكة العربية السعودية

م. حنان محمد أمين طالب
مدرسة العمارة – جامعة شفيلد ، إنجلترا
بريد إلكتروني: Arch.hanan.taleb@gmail.com

ملخص

تهدف هذه الدراسة إلى تحليل استهلاك الطاقة والماء في المباني السكنية بالمملكة العربية السعودية، من أجل تفعيل أسس العمارة المستدامة وتطبيقها في هذا القطاع في المستقبل القريب. من أجل الوصول إلى هذا الهدف، اختيرت احدى المباني السكنية في مدينة جدة كدراسة حالة، وقامت الباحثة بتحليل عميق لإستهلاك الكهرباء والماء عن طريق استخدام برامج المحاكاة. وأفرزت الدراسة عن أخطاء تصميمية عديدة في البيوت السكنية في المملكة والتي أدت بدورها إلى سوء إستخدام الطاقة والماء. قامت الباحثة بتطبيق بعض معايير العمارة المستدامة ومن ثم عمل مقارنة للاستهلاك قبل وبعد تحسين المبنى، وسُلط الضوء أيضاً على تقليل الانبعاثات الكربونية في حالة تطبيق مبادئ الإستدامة في المباني. وأخيراً ثمة توصيات استنتجت من هذه الدراسة وكلها تهدف إلى رسم خارطة طريق لعمارة مستدامة في مباني المملكة العربية السعودية.