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Developing sustainable residential buildings in Saudi Arabia: A case study

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ABSTRACT

This paper assesses the energy and water consumption practices of existing housing in Saudi Arabia, with the ultimate aim of establishing guidelines for delivering sustainable residential buildings in the near future. In order to achieve this aim the current status of a typical Saudi residence (i.e. an apartment complex) is investigated in terms of energy and water consumption using simulation software packages. The paper then examines the prospects for applying various measures to the typical Saudi residence to manage energy and water use more sustainably. 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, to enhance the sustainability of future Saudi residential buildings.

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1. Introduction

With the growing evidence that the phenomena of global warming and climate change are caused by anthropogenic greenhouse gas emissions [1], 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 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 generally given serious consideration with regard to Saudi building designs. In addition, the Kingdom of Saudi Arabia is one of the driest regions in the world and is facing serious challenges relating to a rapid growth in water demand. Against such a background this paper argues that sustainable architecture should be actively and urgently pursued in Saudi Arabia. In order to achieve this goal effort should be made by Saudi architects to minimise a building's water and energy consumption and to do this through the use of climate-responsive designs as well as environmentally friendly renewable energy technologies.

This paper firstly provides an overview of the current status of the Saudi building sector in terms of sustainability. Next, descriptions are given of the research methodology adopted and the apartment complex, which 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 and predicted potential improvements derived from computer modelling. Finally, recommendations 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 residents' quality of life. In principle, sustainable buildings relate to the notion of climate-responsive design. This places an emphasis upon natural energy sources and systems with the aim of achieving building comfort through interactions between the dynamic conditions of the building's environment [2]. For example, the placement of a window in a sustainable building is of the greatest importance as it could provide effective natural light, comfort cooling and ventilation.

Such principles are absent in current Saudi buildings, which are heavily dependent on air conditioning that consumes massive amounts of electricity. As a result of poorly designed buildings in Gulf Cooperation Council (GCC) countries, which include Saudi Arabia, nearly 80% of household electricity is used for air conditioning and refrigeration purposes [3]. 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 [4]. The design of modern

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houses in Saudi Arabia is no longer based on the principles of vernacular architecture. Generally speaking, vernacular architecture tends to emphasise the utilisation of local building resources, as well as the use of passive and low-energy strategies that could lead to reducing the need for both air conditioning and lighting requirements [5]. 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 impacts on air, climate, water and land [6]. 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 [7,8]. Last, but certainly not least, there are no regulations, or compulsory building codes, that incorporate the principles of sustainable architecture, in the country. It has been argued by many scholars that setting a coherent set of these codes and standards is one of the most important and cost-effective ways to promote the widespread of sustainable practices, especially with regard to reducing household energy and water consumption [e.g. 9]. Following the energy crises of the 1970s, such building codes have been widely adopted in developed nations, and more recently in developing countries of Argentina, China and Taiwan. It appears, however, that the sustainable building regulations in some of the countries of the European Union are amongst the most stringent ones. A review of such national codes and building regulations, which is beyond the scope of this current paper, is plentiful in the literature [e.g. 10].

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 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 [11]. 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 [12].

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 air conditioning units running continuously. 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 creates a lack of awareness with regard to environmental concerns as well as a shortage of regulations and policies in terms of sustainable construction implementation. These factors are among the most significant barriers to a flourishing sustainable architecture movement in Saudi Arabia [13]. 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 [14]. Moreover, according to Alzahrani et al. [15], 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 sustainable housing in the country.

3. Methodology

The analysis of this paper is mainly concerned with assessing the current, and potential improvements in terms of, energy and water consumption within houses in Saudi Arabia. A typical residential building (i.e. an apartment complex) was selected to act as a case study for this research. The energy use within the apartment complex was analysed using DesignBuilder software, which is based on the state-of-the-art building performance simulation software entitled EnergyPlus. In essence, DesignBuilder is a commercially available software package, with three-dimensional interface, that provides dynamic and comprehensive energy simulation for buildings. The simulation is based on 'real' hourly weather data, and takes into consideration of both solar gain through windows, as well as heat conduction and convection between zones of different temperatures [16,17]. It is perhaps worth mentioning here that the accuracy of the DesignBuilder software has been validated using the BESTest (Building Energy Simulation TEST) procedure, originally developed by the International Energy Agency. The BESTest is a comparative set of tests that has been regarded by the American Department of Energy and the international community as being a reputable basis for evaluating the capabilities of building energy simulation programs [18].

A three-dimensional DesignBuilder model for the case study was firstly developed based on the building's drawings, and after conducting a site visit as well as intensive consultation with the complex owner, who oversaw the construction of this building himself. The energy consumption within the building was analysed on daily, weekly, monthly and yearly bases. In addition, the DesignBuilder simulation software provided an estimation of the CO_2 emissions, that was calculated based on the type and amount of fuel used to generate the electricity at the building level. In essence, CO_2 emissions are calculated by multiplying fuel consumption by a CO_2 conversion factor. According to the DesignBuilder software, when considering the electricity generation mix in Saudi Arabia, the CO_2 conversion factor is assumed to be 0.685 kg CO_2/kWh. Simulation results were then validated with both actual utility bills and figures obtained from literature. At a later stage, the household energy consumption, and its associated CO_2 production levels, were assessed in order to examine the potential improvements following both the application of a range of energy efficiency measures, and the use of solar PV technology. For the purpose of this analysis, it was assumed that solar PV panels will provide 10% of the household electricity requirements. It is estimated that this conservative figure, which has been set based on economic considerations, can be achieved through fitting only eight PV modules in the building's roof. This estimate is based on the following assumptions that have been adopted from a recent scholarly paper [19]: inverter efficiency 60%, battery efficiency 80%, and that the area of a typical PV module with an output of 75 W is 0.8 m^2 (i.e. 1 m $\times$ 0.8 m). The validity of these assumptions has also been confirmed through contacting several Saudi firms that import, install and maintain solar systems in the country. If the average solar irradiance in Saudi Arabia exceeds 6 kWh/m^2/day [20], the 'annual averaged' output of each module was calculated to be around 216 W (i.e. $75 \times 0.6 \times 0.8 \times 6$). The potential power generation of the eight PV modules was estimated to be 1.73 kW (i.e. No. of modules $\times$ 'annual averaged' output of each module in kW), which would be the equivalent of 15,155 kWh per annum (i.e. 1.73 kW $\times$ 365 days $\times$ 24 h). The latter figure represents 10.4% of the calculated figure for the annual electricity consumption of the building, which will be presented in the analysis part of this paper (Section 5.1). Bearing in mind that the eight PV modules will only occupy 6.4 m^2 of the total roof's area (i.e. 420 m^2), this would leave approximately 98.5% of the roof space

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