Developing sustainable residential buildings in Saudi Arabia: A case study

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**Article Info**

**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.

**Keywords:** Sustainable architecture, Residential buildings, Energy efficiency, Water efficiency

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
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/m³, compared with over $6/m³ 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 subsidised 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 CO₂ emissions, that was calculated based on the type and amount of fuel used to generate the electricity at the building level. In essence, CO₂ emissions are calculated by multiplying fuel consumption by a CO₂ conversion factor. According to the DesignBuilder software, when considering the electricity generation mix in Saudi Arabia, the CO₂ conversion factor is assumed to be 0.685 kg CO₂/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 CO₂ 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 m² (i.e. 1 m × 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/m²/day [20], the ‘annual averaged’ output of each module was calculated to be around 216 W (i.e. 75 × 0.6 × 0.8 × 6). The potential power generation of the eight PV modules was estimated to be 1.73 kW (i.e. No. of modules × ‘annual averaged’ output of each module in kW), which would be the equivalent of 15,155 kWh per annum (i.e. 1.73 kW × 365 days × 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 m² of the total roof's area (i.e. 420 m²), this would leave approximately 98.5% of the roof space
for other activities and/or purposes for the tenants, which may include the possibility of installing additional PV panels.

With regard to water use in the case study, the assessment was largely based on an adapted version of the BRE (i.e. the trade name of Building Research Establishment Limited) Code Water Calculator, which is used as part of the ‘Code for Sustainable Homes’ assessment methodology in the United Kingdom (UK). After undertaking necessary training and examinations in the UK, one of the authors (H.T.) became 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. Throughout this paper, figures of water consumption per capita are expressed in LCD (i.e. litres per capita, per day). The calculated figures for water consumption were then validated with findings from the literature. A number of water saving measures was then suggested in order to reduce the household’s water consumption rates. Finally, the software was run for the purpose of estimating the water saving potential following the application of the measures suggested.

4. The case study

The selected residential building is situated in Jeddah City, which is a diverse and rapidly growing commercial city, located on the Red Sea (latitude 21°30’N and longitude 39°10’E). Jeddah is considered to be an important gateway to the Islamic holy cities of Makkah and Madinah. 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 (see Fig. 1).

When conducting an analysis on the energy use and/or water consumption of a 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 tend to be unbearable towards the end of the summer season. During winter Jeddah maintains its warmth but with reduced humidity and some rain occasionally falling in November and December in small amounts [21]. Detailed information on temperatures and the rather high solar radiation levels in Jeddah throughout the year are given in Fig. 2. These averaged levels represent diurnal (i.e. 24 h) data for each hour of each month.

The case study building comprises of three stories and six apartments, with a built floor area of 420 m² and a total land area of 625 m². Fig. 3 illustrates the floor plans and elevations of the case study.

As shown in Fig. 3 the apartments are elongated and symmetrical around a staircase with a mid-axis perpendicular to the street. Each of the six two-bedroom apartments is occupied by three residents, and is assigned a car parking space in front of the building. From a study of unpublished official statistics provided by the Saudi Ministry of Economy and Planning this apartment complex represents the most common type of residence in Saudi Arabia. Moreover, the materials and construction elements used in the building are the most commonly adopted in the country today (see Table 1).

5. Analysing the case study

5.1. Energy use

The energy use within the case study was analysed using DesignBuilder, and the calculation results for the energy use simulation at the building level on one of the typical summer days of the year in Jeddah (i.e. 15 July) are plotted in Fig. 4. This graph shows temperatures (in °C) at the top, with all actual ‘averaged’ heat balances (in kW) at the bottom. The temperatures shown are the outside temperature, indoor air temperature, radiant temperature and the operative or comfort temperature, which is the average of the indoor air and radiant temperatures. 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 being highest during the late afternoon.

The energy use within the building was also 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 per year, which implies emissions of approximately 101 tonnes of CO₂ per year. The annual electricity consumption per apartment was then obtained by dividing the annual consumption for the building by the number of apartments (i.e. six). Hence, the average annual consumption for each apartment was estimated at around 24,395 kWh per year, with the per capita figure being 8132 kWh per year. Both figures 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 for the year 2008 (see Fig. 5), but the estimate seemed to be a conservative one considering that the typical household electricity consumption for a Saudi apartment was reported to be 20,000 kWh per year.
more than a decade ago [22]. No more recent published estimates for typical electricity use for 2-bedroom apartments in Saudi Arabia appeared to be available in the literature.

5.2. Water consumption

Understanding the current water consumption is the first step in improving water efficiency within the building. As explained in Section 2, the estimation of water use in the case study was largely based on an adapted version of the BRE Code Water Calculator, which determines the average water consumption per capita, depending on the number and type of fittings and appliances installed in a house. Table 2 contains the input figures which were assumed for the purpose of this exercise. These assumptions were based on manufacturer specifications (for items) and real experiments (for additional activities that were not originally considered by the software package).

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 the previous year’s water utility bills were collected and studied, whilst bearing in mind the number of times that private water trucks had to be procured over the previous year. According to the collected water bills the consumption rate over the previous 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. This figure is higher than the anticipated rate of 435 LCD that was forecast a few decades ago [23]. Given that it is comparable to recently reported rates within other GCC countries [e.g. 24–26], 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 [27].

6. Rendering the case study more sustainable

6.1. 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: enhancing the insulation of the 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 wide range of other energy-efficient practices indeed exist around the world, e.g. the use of free cooling to reduce electric load of air conditioning system, as well as the fitting of lighting controls in order to control the light according to the daylight luminance. Nonetheless, re-running the DesignBuilder simulations with the above few modifications showed a significant improvement in terms of energy efficiency, as will be illustrated later in this section.
With regard to the incorporated insulation improvements, the air gaps in the external walls were replaced by foam insulation with a thickness of 100 mm. As a result, the U-value (i.e. thermal transmittance) for the external walls has decreased from 0.58 to 0.33 W/m² K. Moreover, an additional layer of polyurethane insulation (thickness of 100 mm) was added to the roof. Consequently, the U-value for the building’s roof decreased from 1.13 to 0.37 W/m² K. It should be noted here that since the U-values measure the rate of heat transfer through a building element, reducing the U-values should lead to energy savings through lower solar cooling loads. The decisions to include foam insulation to the external walls, and the addition of polyurethane insulation to the roof, were taken after considering the U-values of different construction typologies (see Table 3). It should be noted that the insulation materials below include the ones considered, by Al-Ajlan [28], as being the most commonly produced materials by local manufacturers in Saudi Arabia.

Another important property for improving energy efficiency is thermal inertia (or thermal mass), which represents the capacity of a material to store heat. High thermal inertia walls, whilst not necessarily have good insulation properties, have the ability to provide better indoor comfort through delaying and reducing the impact of outdoor temperature changes on conditioned indoor environments. In other words, walls that are constructed from materials with high thermal inertia will prevent heat to enter indoor by storing it during the day and releasing it during the night when the temperature cools down. It is widely accepted that the use of high thermal inertia walls, with excellent thermal insulation, in buildings would usually result in a reduction of energy requirements for both cooling and heating [29]. Whilst the decision to select construction materials for walls within energy conscious building design should be based on finding a compromise between good thermal insulation and high thermal inertia, this was impossible to accomplish since the most recent available version of DesignBuilder (i.e. version 2.1.0.025) does not calculate thermal inertia for the construction materials involved.

Having made the abovementioned few changes (including insulation improvements) to the model input data, Fig. 6 shows the energy simulation results for the 15th July in order to compare the potential improvement as a result of such modifications. It should be noted that, since the thermal comfort conditions were kept the same as in the initial energy analysis, the reduction of the electrical consumption was merely due to the modifications mentioned above. Obviously, the solar gain 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.

The calculated annual electricity use and resulting CO₂ emissions for the whole building was estimated to be around 98,992 kWh and 69 tonnes CO₂ per year respectively. This translates into a possible 32.4% reduction in annual household electricity consumption as well as 32 tonnes of potential saved CO₂ emissions. In fact, if all the apartment complexes in Saudi Arabia (i.e. over 300,000 buildings based on data provided by the Saudi Ministry of Economy and Planning [30]) had managed to achieve such an attainable level of energy savings, at least 10 million tonnes of CO₂ 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 CO₂ emissions could be reduced by another 7 tonnes per year (see Fig. 7). Given the current high capital cost, however, the use of renewable energy options within the Saudi residential sector might not be economically viable at present. However, their viability could be significantly boosted if the government lifted the large 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 [7].

6.2. Water consumption

There are a number of different ways to reduce such high water consumption within Saudi residential buildings. Table 4 suggests only a few ‘moderate’ modifications to the apartment complex,
7. Guidelines for a sustainable future within the Saudi residential sector

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

- Follow the principles of climate-responsive design, as well as vernacular architecture, when designing new houses in order to improve the energy performance of residential buildings in Saudi Arabia.
- Use sufficient insulation in the building’s walls and roofs. An emphasis should be placed upon selecting materials with good thermal insulation properties, which lead to having both low U-values and high thermal inertia of the construction.
- Use appropriate external shading systems in order to shade residential buildings and their gardens from excessive solar radiation. It should be recognised that effective design and positioning of solar shading devices are not only important to reduce undesirable solar gain, but also to utilise natural light for indoor illumination.
- Place windows in such a way as to maximise the utilisation of natural light and thereby lessen 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.
- Integrate zero-carbon energy technologies such as solar PV and/or wind turbines if feasible. This indeed should not underplay the possibility of other, and perhaps low-cost, energy saving options such as the fitting of solar-based domestic water heaters, the utilisation of wasted heat from air conditioning for domestic heating (or preheating the mains water supply), as well as the use of free cooling (if compatible with the type of air conditioning system employed).
- Use energy-efficient appliances and lighting equipment (e.g. use of fluorescent lights instead of incandescent lamps). Based on this study’s findings, it is recommended that at least 70% of the building’s lighting should be of the fluorescent type.
- Make use of water-saving means, such as low-consumption sanitary fittings and controls, as well as incorporating grey water recycling equipment in design of Saudi residential buildings. In this regard, this study reveals that the potential daily savings per capita that could result from fitting low-flow tap aerators, a grey water system and efficient washing machines are estimated to be 21.2%, 7.7% and 7% respectively.
- In addition to the above design-related recommendations, the following are general, yet relevant, guidelines which could also contribute towards achieving sustainability within the residential section of Saudi Arabia:
  - 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.
  - Promote household waste recycling schemes, which currently do not exist in the country.
  - At the building design stage, only recycled and responsibly sourced construction materials should be selected.
  - Launch intensive electric and water rationing schemes.
  - Initiate public awareness programmes on the need for conserving natural resources and the importance of recycling.
  - Implement building regulations, compulsory codes and standards that promote energy efficiency in buildings.
  - Impose strict plumbing codes and penalties for wasting household water, as well as removing the consumer price subsidies on conventional fossil-based electricity.
  - Encourage the use of energy- and water-efficient household appliances, whose prices could be subsidised by the government.
  - 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).
  - Allocate the necessary resources to enhance awareness with regard to sustainable architecture among architects, engineers and the general public.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Assumed input data for water consumption analysis.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>2 x basin taps</td>
</tr>
<tr>
<td>Fixed-cistern</td>
<td>Capacity: 8 l</td>
</tr>
<tr>
<td>Bidet</td>
<td>Consumption: 2.64 l/use</td>
</tr>
<tr>
<td>Shower</td>
<td>Flow rate: 18 l/min</td>
</tr>
<tr>
<td>Bath</td>
<td>Capacity to overflow: 225 l</td>
</tr>
<tr>
<td>2 x kitchen sink taps</td>
<td>Flow rate: 15 l/min</td>
</tr>
<tr>
<td>Washing machine</td>
<td>Consumption: 15 l/cycle</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Activity</th>
<th>Abulation Consumption: 26 LCD (L/min per capita per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toilet cleaning</td>
<td>Consumption: 21 l/toilet per day (i.e. 14 LCD)</td>
</tr>
<tr>
<td>Car washing</td>
<td>Consumption: 126 l/car per week (i.e. 6 LCD)</td>
</tr>
<tr>
<td>Irrigation/courtyard cleaning</td>
<td>Consumption: 252 l/building per week (i.e. 2 LCD)</td>
</tr>
<tr>
<td>Total: 498 LCD</td>
<td></td>
</tr>
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</table>

Table 3 | Assessing U-values of the external walls and roof after applying different insulation materials. |
<table>
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<tr>
<td>Modification</td>
<td>Potential saving (in LCD)</td>
</tr>
<tr>
<td>Low-flow tap aerators in the kitchen (9 l/min)</td>
<td>63.5</td>
</tr>
<tr>
<td>Low-flow tap aerators in the bathroom (6 l/min)</td>
<td>42.3</td>
</tr>
<tr>
<td>Low-flow cisterns (9 l/min)</td>
<td>27.0</td>
</tr>
<tr>
<td>Dual-flush (6/4 l) cisterns</td>
<td>16.0</td>
</tr>
<tr>
<td>Efficient washing machines (49 l/min)</td>
<td>34.7</td>
</tr>
<tr>
<td>A grey water system, which collects 90% of the bath and shower waste in order to supply to toilet cisterns</td>
<td>38.4</td>
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<td>Total</td>
<td>221.9</td>
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that the large consumer subsidies in the current price of electric-
tainment measures in Saudi houses. It is therefore recommended
awareness, which could determine the successful adoption of sus-
nomic incentive, among other factors, such as enhanced public
tries, reducing household energy and water consumption makes a
8. Conclusions
Around the world, especially in sustainability pioneering coun-
tries, reducing household energy and water consumption makes a
great deal of economic sense. It could be argued that it is the eco-
nomic incentive, among other factors, such as enhanced public
awareness, which could determine the successful adoption of sus-
mination measures in Saudi houses. It is therefore recommended
that the large consumer subsidies in the current price of electric-
ity and water should be reduced or removed in order to rational-
ise energy and water consumption within the Saudi residential
sector. This study, which has examined in detail a typical Saudi
residential building (i.e. apartment complex), not only shows that
such a building severely lacks the means to ensure energy and
water efficiency, but that it also demonstrates how a few design
and operational changes could have had a significant impact on
the sustainability performance of the building. The energy conserv-
ervation measures, considered in this paper, were: improving ther-
mal insulation of the external walls and roofs; more efficient glazing; fitting external shading devices; and fitting energy-effi-
cient fluorescent lighting. Suggested water conservation measures
included the use of low-flow taps in kitchens and bathrooms;
low-flow showerheads; efficient washing machines; and the
installation of a grey water system. It is estimated that applying
these measures in the apartment complex, under consideration,
could collectively achieve energy consumption reductions of
around 32.4% (in addition to an annual CO2 reductions of 32 ton-
nes per annum), as well as a potential 55.4% reduction in terms of
water consumption rates. Finally, having identified many short-
comings common to the current design of Saudi dwellings, this
paper has put forward a number of strategies which should help
towards the development of a more sustainable residential sector
in Saudi Arabia.

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Table 4
Suggested water-saving devices.

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Fig. 6. Temperature and heat balance of the building after modifications (15th July).

Fig. 7. Potential CO2 emission reductions for the case study.


