Trends in Residential Energy Consumption in Saudi Arabia with Particular Reference to the Eastern Province

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ABSTRACT

Residential buildings are vital in the energy scenario of Saudi Arabia as they account for 52% of the total electricity consumption. The Eastern Province, due to its harsh weather conditions, is one of the most challenging areas in Saudi Arabia in terms of residential energy consumption. The province is vital also because of its large land area, accounting for almost one third of the entire country. This article investigates some of the important factors related to the residential energy consumption i.e. weather conditions, types of dwellings, building envelops, air-conditioning (A/C) systems and domestic appliances especially cooking ovens. The work is based upon an analysis of the actual monthly electricity consumption for 115 dwellings in Dhahran for the year 2012. The investigated buildings include 62 apartments, 28 villas, and 25 traditional houses. The annual average electricity consumption for the surveyed dwellings was found to be 176.5 kWh/m², a value higher than international energy-efficiency benchmarks. It is found that the use of mini-split A/C systems, thermal insulation and double-glazed windows can help reduce the electricity consumption by over 30%.

KEYWORDS

Domestic energy consumption, Air-conditioning systems, Thermal insulation, Window glazing systems, Cooking energy, Saudi Arabia, Dhahran.

INTRODUCTION

The building industry has a key role to play in achieving sustainable development in any country [1]. Buildings contribute to environmental issues ranging from the excessive use of resources during the construction and the operation stages to polluting the surrounding environment [2]. Buildings not only use resources such as energy and raw materials but they also generate waste and potentially harmful atmospheric emissions [3]. Buildings are responsible for a substantial proportion of the global greenhouse gases (GHGs) emissions. For example, according to the United Kingdom Government, around 40% of the national energy consumption and carbon dioxide emissions (CO_2) are associated with buildings [4]. Buildings account for 40% of the total energy consumption at the European Union (EU) level as well [5]. In the wake of such a crucial role of buildings in its energy and environmental scenario, the EU through its 20-20-20 Directive has set 20-20-20 targets. Specifically, these targets aim to achieve by 2020 a 20% reduction in EU greenhouse gas (GHG) emissions from 1990 levels; raising the

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share of EU energy consumption produced from renewable resources to 20% and a 20% improvement in the EU's energy efficiency [6]. Similarly, the United States (US) Green Building Council [7] suggests that the US commercial and residential building sector accounts for 39% of CO_2 emissions per year, more than any other sector in the country. According to Alnaser *et al.* [8], construction and operation of buildings have an enormous direct and indirect impact on the environment. The annual environmental impact of the global building sector includes energy use (42%), atmospheric emissions (40%), raw materials use (30%), solid waste (25%), water use (25%), water effluents (20%), land use (12%), and other emissions (13%) [8]. Given the massive growth in new construction and the inefficiencies of existing building stock worldwide, in a business as usual scenario, the level of GHGs emissions from buildings is set to rise in future [3]. If the desired targets for GHGs emissions reduction are to be met, emissions from the building sector need to be tackled with much greater seriousness and vigour than the past efforts and in this respect energy-efficient and sustainable buildings are critical to be promoted. In order to develop robust strategies to stimulate the take up of energy-efficient buildings, it is crucial to have a thorough understanding of current practices and future trends in the building sector.

ENERGY CONSUMPTION IN SAUDI ARABIA

The total installed electricity generation capacity in Saudi Arabia is 44,485 MW, all being supported by oil and natural gas with a respectively share of 57% and 43% [9]. In the wake of fluctuating oil prices in recent years, natural gas has seen a jump in its share in electricity production - the contribution from natural gas has increased from 37% in 2007 to 43% in 2009 [10].

The demand for electricity is experiencing a rapid growth in Saudi Arabia. Since 1990, for example, the demand has increased at an annual rate of 6% [9]. Due to the economic and population growth, statistics suggest that, in comparison to 2008, the primary energy demand is expected to increase by 50% in 2020 [11]. Furthermore, the per capita electricity consumption is also increasing rapidly due to factors like urbanization, subsidized tariffs and increased use of energy intensive appliances as shown in Figure 1a [9]. The residential sector is the biggest consumer of electricity - presently it accounts for 52% of the total national electricity consumption [9] as indicated in Figure 1b and it is expected that by year 2025 the demand from this sector would double [12]. The rapid growth in electricity demand is largely due to inefficient use of electricity which in turn is associated with extremely subsidized tariffs as also highlighted by Alyousef and Stevens [13]. To respond to the electricity growth trend, the country needs to take appropriate initiatives not only to boost its power generation capacity but also to make residential sector more energy efficient.

An analysis of the construction sector suggests that most of the projects being undertaken are residential buildings in order to meet the demand for new homes - the statistics provided by the Ministry of Municipal and Rural Affairs indicate that the majority of licenses issued for construction in Saudi Arabia are for residential buildings [14]. In addition, the residential sector is set to experience a similar growth in future as the Saudi population is rising at a rate of 2.5% per year and only 24% of the Saudi nationals have their own homes [15]. Estimates suggest that around two-third of the population is under the age of 30 years [16]. To meet the needs of the constantly growing population, the country needs to build 2.32 million new homes by 2020 [17].

In a survey undertaken by the Government, it was discovered that about 60% of the total electricity consumed in summer goes into air conditioning (A/C) systems [18]. According to the Saudi Ministry of Water and Electricity [9], the electricity consumption in the country has increased by 35% over the last two decades largely due to intensive use of air conditioning in summer. It is therefore crucial for Saudi Arabia to improve the energy consumption trends in residential buildings and to move towards energy efficient buildings. This paper aims to discuss the energy trends in the Saudi residential sector based upon a survey of the actual monthly electricity consumption for 115 housing units in the Eastern Province.

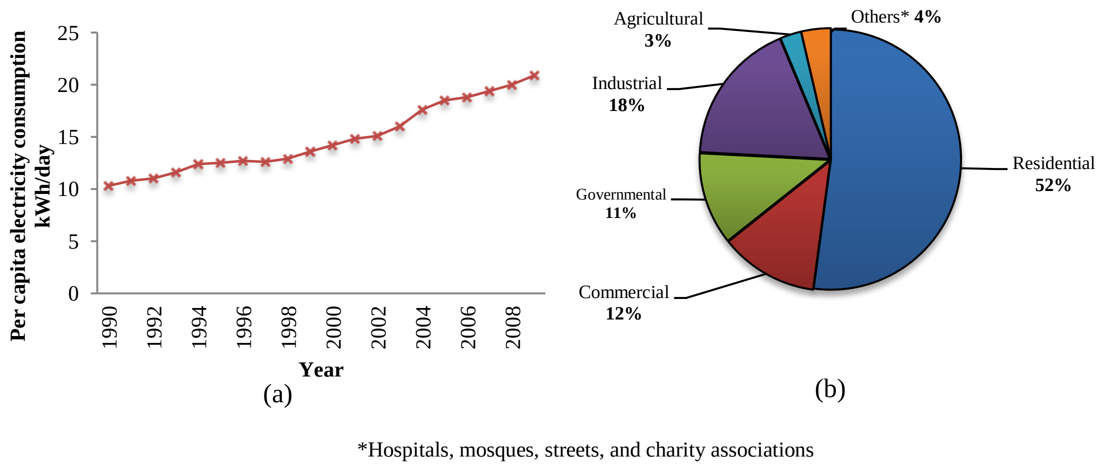


Figure 1. Per capita electricity consumption in Saudi Arabia (a); Electricity consumption by sector (b)

Saudi Arabia can be classified climatically into five different inhabited climatic zones: Subtropical with a Mediterranean subzone and Mountainous subtype (for example Khamis Mushait); Hot-Dry with a Maritime Desert subzone (for example Jeddah); Hot-Dry Maritime subzone (for example Dhahran); Cold-Dry with a Desert subzone (for example Quriat), and Hot-Dry with a Desert subzone (for example Riyadh) [19]. The Eastern Province is a vital region in Saudi Arabia because of its large land area, accounting for almost one third of the entire country. Due to its harsh weather conditions, it is one of the most challenging areas in Saudi Arabia in terms of residential energy consumption. Dhahran is a main representative city in the Eastern Province which is subject to Hot-Dry Maritime weather subzone with the maximum temperature highest among all climatic zones (see Table 1).

Table 1. Temperature comparison between Saudi represented climatic zones [20]

Location	Maximum dry-bulb temperature (°C)	Mean dry-bulb temperature (°C)
Dhahran	45.7	25.8
Guriat	43.9	19.8
Riyadh	43.7	25.12
Jeddah	41.7	27.9
Khamis Mushait	34.3	18.9

SURVEY

To investigate the energy consumption trends in residential buildings, the study undertook a survey of dwellings in the Dhahran region on the basis of monthly electricity bills. Through the questionnaire based survey, randomly selected dwellings were investigated for their monthly electricity consumption from January to December 2012.

The survey also looked into eight main electricity consumption related features: dwelling type, dwelling age, dwelling conditions area, type of A/C system, thermal insulation, window glazing system, and fuel for cooking. A total of 128 responses were received of which 13 were rejected for incomplete information. The survey data was gathered through in-person approach using various modes including interviews of residents/inhabitants, investigation of building plans and electricity bills and walk through the buildings.

In hot-humid climate, similar to Dhahran, A/C and building envelop significantly influence the energy consumption in buildings [21-23]. In Saudi dwellings, the A/C system and cooking are the two most important energy consuming factors, collectively accounting for more than 80% of total household energy consumption [18-24]. The envelope system for housing in Dhahran region is typically made of concrete while the external walls from hollow-block and the roof are made of rapid-slab/Hordi-slab [25]. In Saudi dwellings, thermal insulation is usually applied in external walls and is unlikely to be applied within roofs and slab on grade [23-26]. The most common thermal insulation materials are Polystyrene and Polyurethane with a typical thickness of 5 centimeters [27]. Due to lack of data on the type of insulation used in the surveyed dwellings, all of them are assumed to have similar insulation while it is noteworthy that both of the aforementioned insulations are quite similar in performance [27, 28].

RESULTS AND ANALYSIS

The types of dwelling studied in the survey are apartments, traditional houses and villas representing over 90% of the dwellings in the Eastern Province [29]. A traditional house in Saudi Arabia is a dwelling that has at least one external wall is shared with a neighbour and does not have a fence (i.e. 100% of the land is built). The villa is a free-standing (detached) residential building surrounded by fence. Generally, the type of dwelling for more than half of the responses is apartment (see Figure 2a). Over half of the surveyed dwellings were built within the last ten years (see Figure 2b).

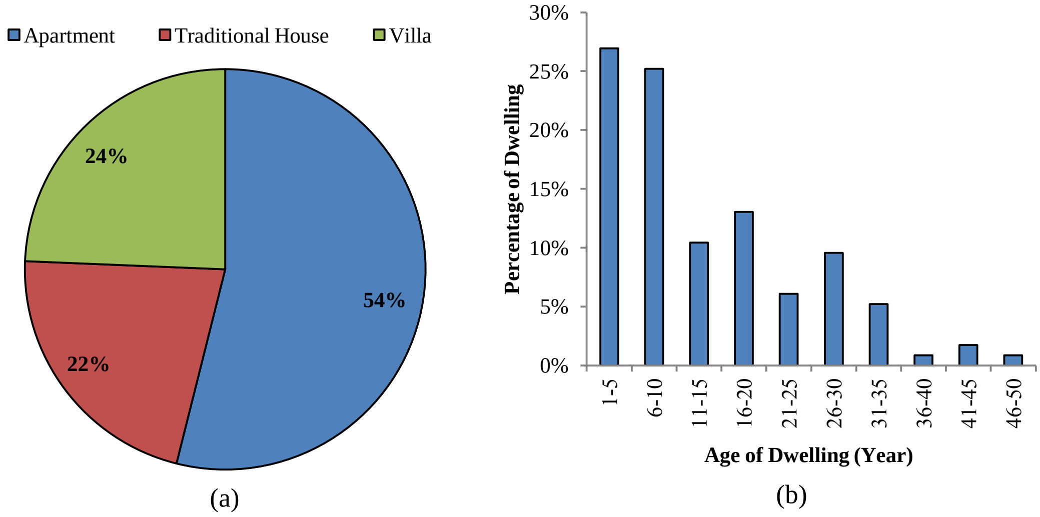
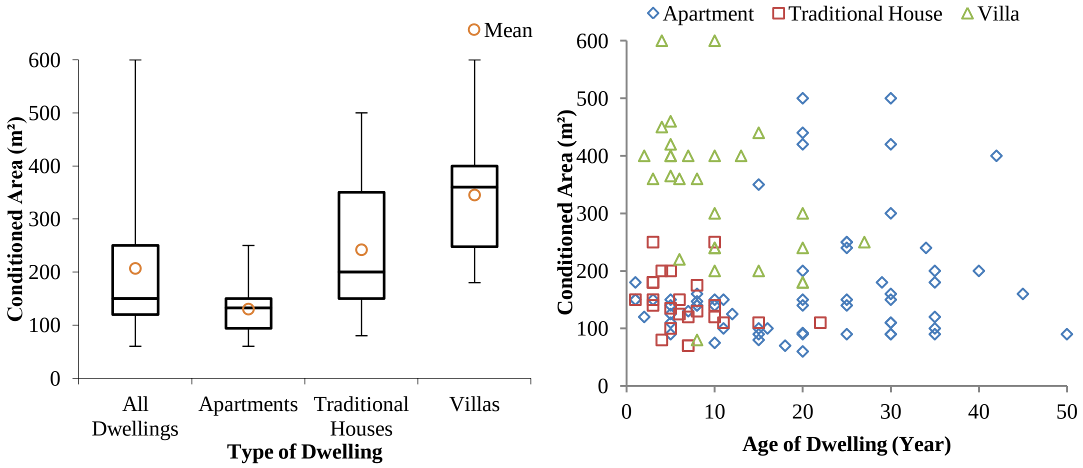


Figure 2. Surveyed dwellings by type (a); Percentage of surveyed dwellings in terms of age (b)

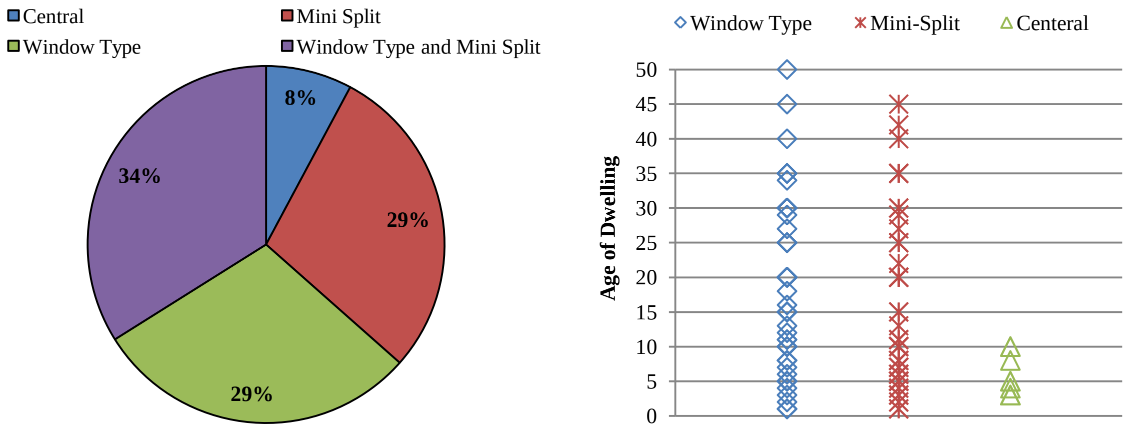
The survey results indicate that the average conditioned area for the surveyed dwellings is about 200 m². Of these, apartments and villas respectively account for the smallest and the largest conditioned areas (see Figure 3a). It is also observed that the conditioned area for the surveyed villas and traditional houses - all built over the last three decades - has increased in recent years as shown in Figure 3b. On the other hand, the conditioned area for apartments has decreased during the last two decades (see Figure 3b).



(a) (b)

Figure 3. Box-Plot of the conditioned area for all type of dwellings (a); Conditioned area for all dwellings in terms of age (b)

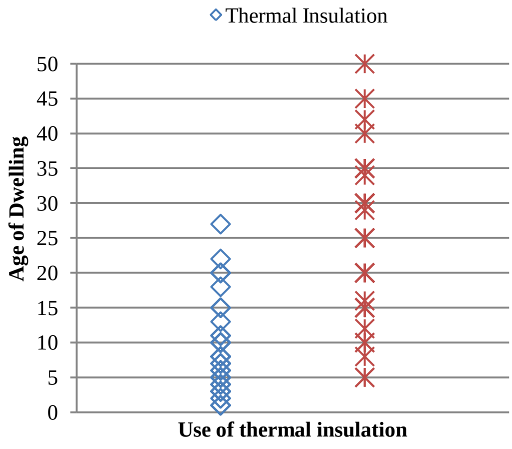
The survey results reveal that about 92% of the surveyed dwellings are using mini-split and window-type (conventional type of A/C units that are fixed in a window frame through the walls) A/C systems (see Figure 4a). It is also observed that compared to mini-split and window-type systems, use of central systems is a recent phenomenon (see Figure 4b). It is also observed that apartments and villas employ window-type and mini-split systems, while the traditional houses mainly go for the window-type systems. It is also seen that the central systems are mainly used in apartments and villas as none of the surveyed traditional houses employed this type of system.



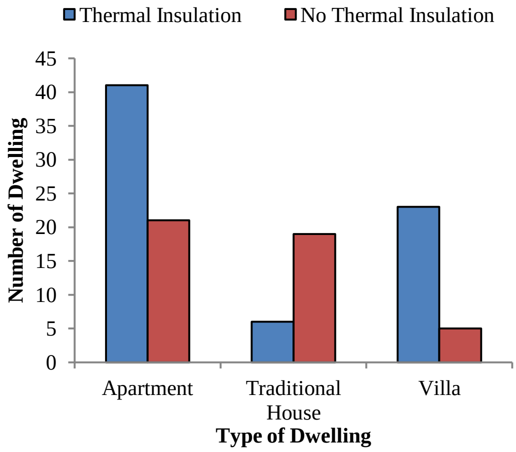
(a) (b)

Figure 4. Surveyed dwellings by type of A/C systems (a); Surveyed A/C systems in terms of age (b)

The survey results indicate that the thermal insulation is used within 61% of the surveyed dwellings. It is also observed that the use of thermal insulation started two decades ago and none of the dwellings built over the last five years is thermally un-insulated (see Figure 5a). It was revealed that more than half of the apartments and most of the villas were thermally insulated. On the other hand, more than 75% of the traditional houses were without insulation (see Figure 5b). Moreover, it was found that dwellings employing window-type A/C systems are mostly without thermal insulation.



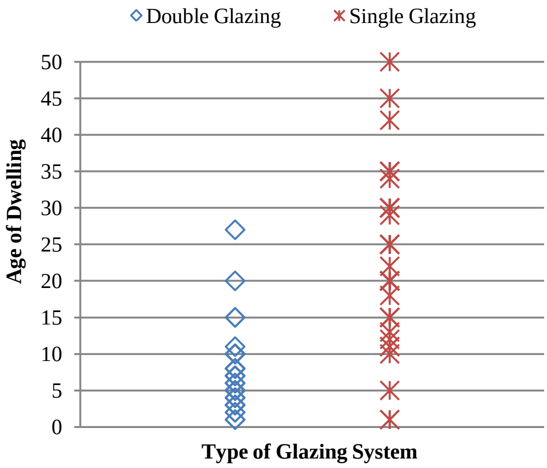
(a)



(b)

Figure 5. The use of thermal insulation in terms of age (a); The use of thermal insulation in terms of type of dwelling (b)

In terms of the window glazing system, the main focus was on the number of glazing layers. It was found that double-glazed system is used within 50% of the surveyed dwellings. The survey results show that while the use of double-glazed system has increased over the last decade, single-glazed windows are still being applied (see Figure 6a). It was also observed that more than two-thirds of the villas and more than half of the apartments used double-glazed windows, while only 4 of the 25 traditional houses surveyed in the study were using double-glazed system (see Figure 6b).



(a)

(b)

Figure 6. Surveyed type of glazing systems in terms of age (a); Surveyed type of glazing systems in terms of type of dwelling (b)

In terms of cooking fuels, both gas and electricity are used in Saudi dwellings. About 60% of the responses in this study suggested the use of gas for cooking while the rest used electricity. It is also found that the use of electricity for cooking has become common over the last decade (see Figure 7a). The survey results also revealed that electric cooking is more common in apartments as about 60% of the apartment responses indicated to be using it while most of the villas and traditional houses suggested to be using gas (see Figure 7b).

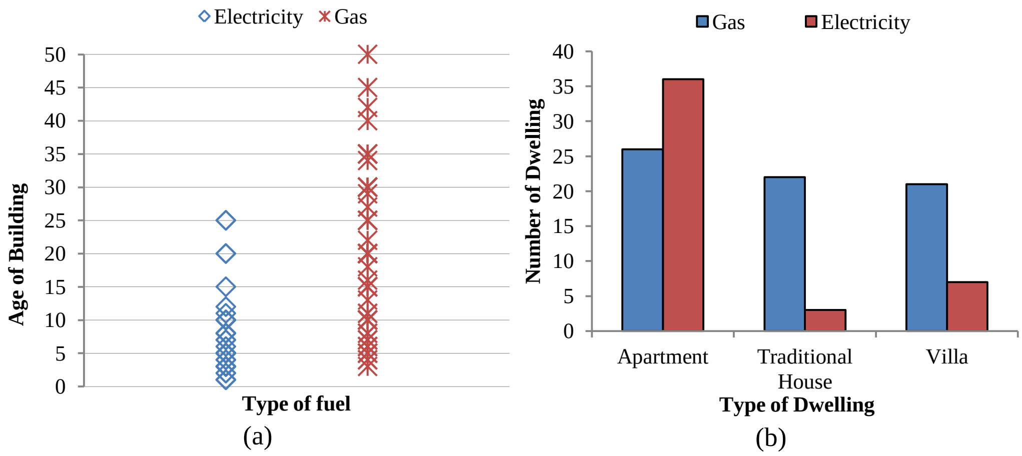


Figure 7. Surveyed type of fuel for cooking in terms of age (a); Surveyed type of fuel for cooking in terms of type of dwellings (b)

The overall electricity consumption for the surveyed dwellings is found to be between 27 and 401 kWh/m²/year whereas the average value is calculated to be 176.5 kWh/m²/year. The electricity consumption for 43% of all dwellings is reported to be between 125 and 174 kWh/m²/year (see Figure 8a). In terms of type of dwellings, the average electricity consumption for apartments, traditional house, and villas is respectively, 196.5, 156.5 and 150 kWh/m²/year (see Figure 8b). It is observed that the annual electricity consumption per square meter for apartments tends to be higher than the other types.

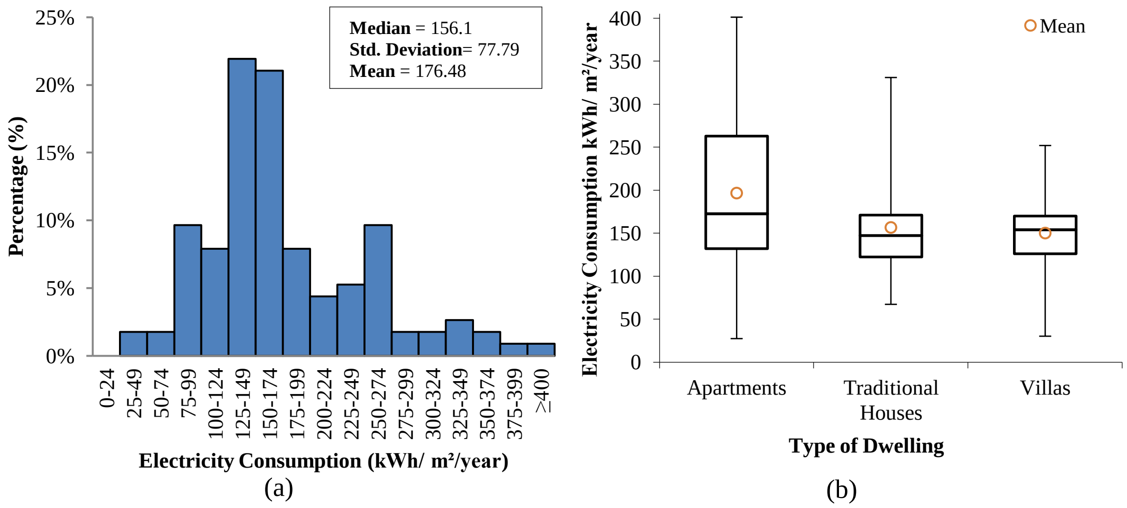


Figure 8. Distribution of electricity consumption for all survey dwellings (a); Box-Plot of electricity consumption for all type of dwellings (b)

Furthermore, it was observed from the analysis that the average of electricity consumption for dwellings using electricity as source of energy for cooking is about 34% much higher than dwelling that uses gas (see Figure 9a). The average of electricity consumption for dwellings with mini-split system was found to be almost half the electricity consumption for dwellings with central system or window-type system (see Figure 9b).

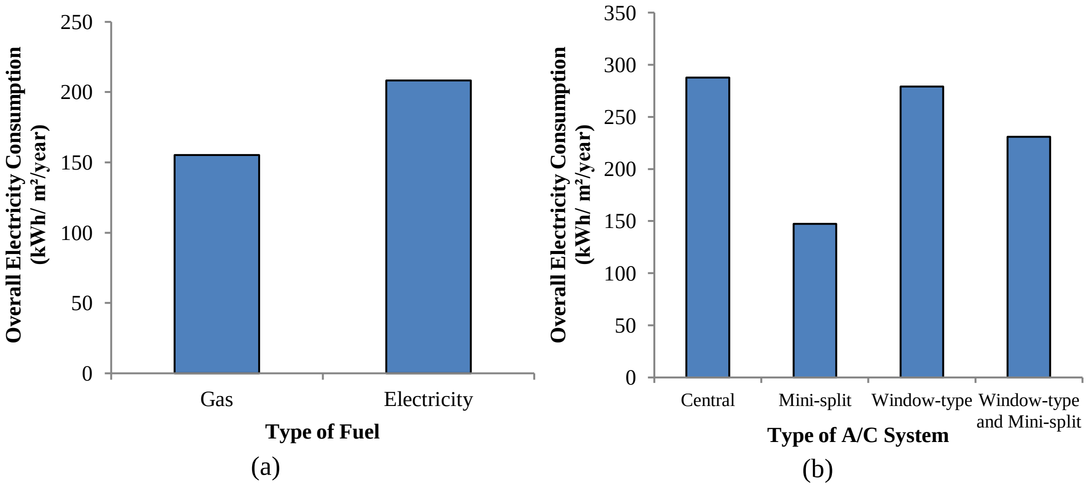


Figure 9. Average electricity consumption in terms of cooking fuel (a); Average electricity consumption in terms of type of A/C system (b)

The average electricity consumption for dwellings with thermal insulation is about 32% lower than the dwellings without thermal insulation (see Figure 10a). About 87% of the surveyed dwellings with thermal insulation employed double-glazed window systems. The average electricity consumption for dwellings with double-glazed windows is about 35% lower than the dwellings with single-glazed window (see Figure 10b). Around 94% of dwellings with double-glazed windows are thermally insulated.

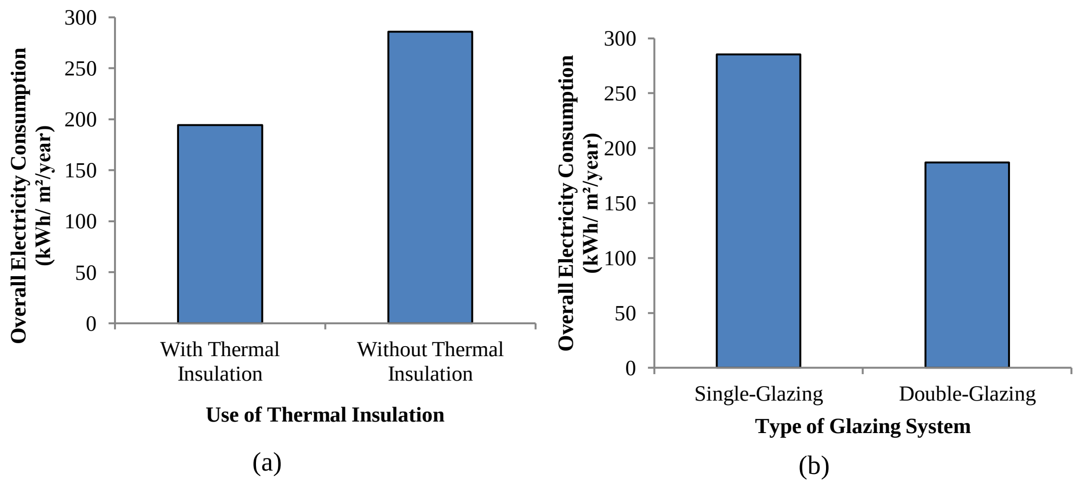


Figure 10. Average electricity consumption in terms of use of thermal insulation (a); Average electricity consumption in terms of type of glazing system (b)

In terms of overall electricity consumption, the survey results reveal that the annual electricity consumption per square meter especially for apartments and traditional houses decreases when the conditioned area increasing and vice versa (see Figure 11a). It is also observed that the electricity consumption of new homes tend to be higher in comparison to the old ones (see Figure 11b).

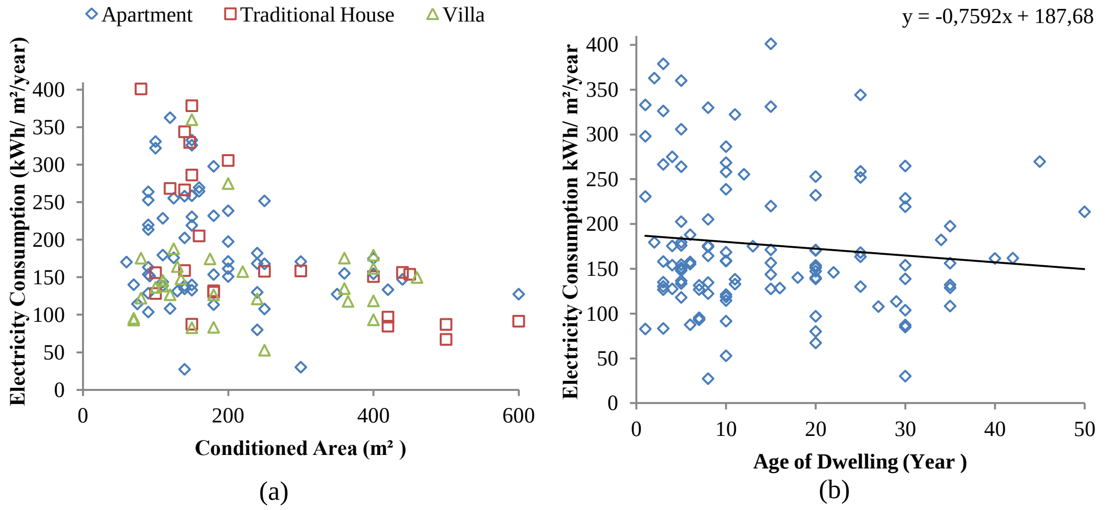


Figure 11. Annual electricity consumption per square meter for all type of survey dwellings (a); Linear regression for electricity consumption with age of dwelling (b)

DISCUSSION AND CONCLUSIONS

The study highlights some energy consumption and efficiency trends in the residential sector in Dhahran region of Saudi Arabia. Among the three dwelling types in this study (i.e. apartments, traditional house and villa), villas and traditional houses tend to have lower electricity consumption per square meter compared to apartments. However, the apartment average conditioned found out to be 130 m² while villa and traditional house found to be 345 and 240 m² respectively. The average of electricity consumption for villas and traditional houses are close, despite most of the surveyed traditional houses were using window-type system, single-glazed windows, and un-insulated external walls. This could be due to the fact that traditional houses have less exposed area to the harsh weather conditions and more shading on external walls.

In Saudi Arabia, four types of A/C systems are mainly used in residential buildings: window-type, mini-split, central and evaporative cooler [25]. Given the fact that the Eastern Province is subject to high humidity [20], the use of evaporative cooling system is limited. While the A/C in the Eastern Province is largely dominated by window-type and mini-split systems, the use of central systems has started to emerge over the last few years. The survey results reveal that dwellings with mini-split system have about half the annual electricity consumption for dwellings using window-type and central systems. However, only 29% of the surveyed dwellings are using mini-split system, and 34% of them use mini-split in conjunction with window-type systems.

The application of thermal insulation and double-glazing systems has become common over the last 20 years. This might be due to the encouragement by the Saudi Government through increasing the public awareness about the importance of energy efficiency and thermal insulation. In 1985, the Saudi Government started to pay attention to the significance of thermal insulation and its impact on the energy saving [11]. Subsequently a number of policy initiatives have been taken to promote the cause. For example, in 1994, it was made mandatory for all government projects to have thermal insulation [30]. Thereafter, in 2010, it became a mandatory requirement for all new dwelling to have insulated external walls [31]. These initiatives appear to have a positive impact on the increased use of thermal insulation across the board including the residential sector.

It is also observed that the use of electric cooking has become common over the last decade. Although, the use of natural gas is less harmful for the environment in comparison with fossil fuel based electricity, the use of the latter is becoming more and more common for cooking needs [32]. Presently, there is no gas pipeline network in Saudi Arabia and the provision of gas is through refillable cooking gas cylinders, and this could be an important factor in the promotion of electric cooking in recent years.

The annual average electricity consumption for the dwellings surveyed in this study was found to be 176.5 kWh/m². In a global perspective, this value appears to be quite high. For example, it is higher than its corresponding value in the US's hot-humid climate (i.e. the southern part of the US), which is about 130 kWh/m² [33]. It is also higher than the international benchmark values for energy-efficient residential buildings - the maximum annual primary energy demand for passive houses being120 kWh/m² [34] and about 90 kWh/m² for Zero-Energy Homes [35].

In order to increase the energy-efficiency in the Saudi residential sector some energy issues are required to be tackled further. It has been indicated from this survey that the use of mini-split A/C system, thermal insulation in external walls, and double-glazed windows can help in reducing the electricity consumption by over 30%. The use of mini-split A/C systems in dwellings should be encouraged and other types of A/C especially the central system should be avoided. The stimulation program to use thermal insulation should stay alive and attention should be paid to other factors such as the application of thermal insulation in roof and the use of double-glazing windows.

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