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Determining the Household Electricity Demand for Energy Conservation in Various Desert Climates

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Abstract—*The building industry have a strong interaction with the global energy and environmental scenarios. Buildings are responsible for more than 40% of global energy consumption and over a third of the total global greenhouse gases emissions. Hot desert regions, like Saudi Arabia, are very challenging in terms of building energy consumption. The role of the housing sector in the country is critical as it accounts for half of the total national electricity consumption. Therefore, it is vital to apply energy conservation principles in this sector. Nevertheless, a systemic investigation of electricity demand is essential to identify areas which need to be focused on in terms of energy conservation. To determine these areas, a hypothetical house is designed, modelled and compared with measured electricity values. Integrated Environmental Solutions <Virtual Environment> software is employed to simulate the hypothetical house in the five climatic zones of Saudi Arabia that are represented by Dhahran, Guriat, Riyadh, Jeddah and Khamis Mushai. The investigation focuses mainly on the building services systems and envelope systems. The findings reveal that the annual electricity demand for homes in Dhahran, Guriat, Riyadh, Jeddah, and Khamis Mushait is 129 kWh/m², 91 kWh/m², 112 kWh/m², 165 kWh/m², and 60 kWh/m², respectively. It also reveal that the electricity demand mainly comes from heating, ventilation and air-conditioning system, domestic equipment and lights in all models. Domestic hot water observed to be the least demanding parameter in all models. A further investigation reveals that though results may vary from location to location, the important factors in all models are internal gain, solar gain, external conduction gain, and infiltration gain.*

Keywords—Electricity Demand; Energy Conservation; Building Energy; Desert Climates; Saudi Arabia.

I. INTRODUCTION

The world faces a string of serious energy and environmental challenges. Fossil fuel reserves, presently contributing to over 80% of the world's total primary energy consumption, for example, are declining, the demand for energy is on a steep rise and energy prices are fluctuating and rising [1]. The global primary energy consumption is reported to have increased by 29% from 2000 to 2010 and is forecasted to see a further 20% jump by 2020 [2]. While there are growing concerns about security of energy supplies, the environmental security is also one of the biggest threats for the planet. The global energy and environmental scenarios are closely interlinked; the problems with the supply and use of energy are related to wider environmental issues including global warming.

Buildings and construction industry have a strong interaction with the global energy and environmental scenarios. Buildings are responsible for more than 40% of global energy consumption and over a third of the total global greenhouse gases (GHG) emissions [3]. A building uses energy throughout its life (i.e. from its construction to its demolition). The demand for energy in buildings in their life cycle is both direct and indirect. Direct energy is used for construction, operation, renovation, and demolition in a building; whereas indirect energy is consumed by a building for the production of material used in its construction and technical installations [4], [5]. The residential sector alone represents 26% and 17% of world energy consumption and carbon dioxide (CO_2) respectively [6]. Given the crucial role residential sector can play towards mitigating the energy and environmental issues, the application of energy conservation concepts in this sector has received significant attention across the world [7].

One third of world's land is located in desert region [8]. Hot deserts are amongst the most challenging regions in terms of energy consumption in buildings due to the intensive demand for cooling as it experiences an extreme maximum air temperature of over 50 °C [9]. Saudi Arabia is an example of a hot desert country which lies between 31°N - 17.5°N latitude and 50°E - 36.6°E longitude. Saudi Arabia has many climatic zones that can represent various hot desert subzones. In addition, its residential sector is set to experience a strong 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 [10]. Estimates also suggested that around two-thirds of the population is under the age of 30 years [11]. To meet the needs of the constantly growing population, the country needs to build 230 thousand new homes annually through to 2020 [12]. Currently, the Ministry of Housing is planning to build 500 thousand housing units in the major cities of Saudi Arabia [13].On the other hand, the residential sector in Saudi Arabia responsible for 50% of the total national electricity consumption [14]. Therefore, it is essential to apply energy conservation concepts in this sector. However, in order to achieve this, a systemic investigation of electricity demand is essential to identify areas which need to be focused on in terms of energy conservation.

This work aims to determining the household electricity demand for energy conservation in various desert climates taking Saudi Arabia as an example. Particularly, a systemic investigation of electricity demand was undertaken to identify areas which need to be focused on in terms of energy conservation. This investigation focuses mainly on the building services systems and envelope systems. In order to fulfill this, a hypothetical house is designed, modelled and compared with measured electricity values. Integrated Environmental Solutions <Virtual Environment> (IES <VE>) software is employed to simulate the hypothetical house in all climatic zones of Saudi Arabia.

II. Climatic Zones of Saudi Arabia

Saudi Arabia is a large country with an area of 2.3 million square kilometres and a land elevation that varies from 0 to 3,000 meter above the mean sea level [15]. With such a large land area and variation with regards to sea level, different parts of the country have distinctive climatic features as are clearly noticeable in day to day life. Over the years Saudi Arabia has been regionalized climatically by scientific and administrative bodies in several ways- it has been classified individually, part of the GCC Countries, part of the Arab World and part of the Middles East North Africa (MENA) region [16]. Majority of these classifications described the country either as a desert or arid region (i.e. as one or two climatic zones). Köppen-Geiger, for example, has classified the country in two climatic zones including desert cold arid zone in the south-western region and the remaining as a desert hot arid zone [17]. This simple description is misleading as it conceals significant climatic differences amongst various regions of the country.

Said et al. classifies the country into six climatic zones [18]. Given the fact that the Empty Quarter is an uninhabited region; five locations are selected as representative of the five habited climatic zones: Dhahran, Guriat, Riyadh, Jeddah and Khamis Mushait. Fig.1 and Table 1 show the representative cities and the climatic characteristics of these climatic zones.

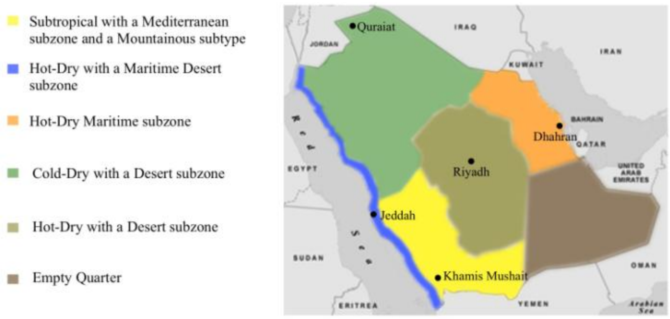

Fig. 1. The climatic zones in Saudi Arabia [18].

TABLE 1. The climatic parameters for the climatic represented locations [19]

Climatic represented location	Geographic coordinates			Air temperature			Relative humidity		
	Latitude (°N)	*Longitude (°E)*	*Elevation (m)*	*Minimum (°C)*	*Maximum (°C)*	*Mean (°C)*	*Minimum (%)*	*Maximum (%)*	*Mean (%)*
Dhahran	26.3	50.1	22	5.0	45.7	25.8	19	99	57
Guriat	31.3	37.4	502	-3.3	43.9	19.8	12	100	40
Riyadh	24.7	46.8	583	2.2	43.7	25.1	10	91	32
Jeddah	21.5	39.2	33	13.9	41.7	27.9	37	100	65
Khamis Mushait	18.3	42.7	2051	2.7	34.3	18.9	17	100	51

III. The Study Model

The present work aims to determining the household electricity demand for energy conservation in the five Saudi climatic zones. In order to achieve this, a virtual (base) house was modelled in all concerned locations using IES <VE>. The weather files used in the simulation were extracted from Meteonorm 5.1. The Meteonorm generates hourly time series for the desired location on the basis of well-validated models and data banks of tens of years [19].

The model in this study was designed on the basis of a detailed questionnaire survey that was undertaken to determine the aspired dwelling in Saudi Arabia. The participants were selected randomly from different regions covering all climatic zones in Saudi Arabia. Survey participants were asked about the type, size, number of floors, and functional spaces of their possible future (inspired) dwelling. The survey was conducted between December 2011 and February 2012. A total of 453 responses were received from dwelling users employing web based and in-person approach. The majority of the questionnaire survey participants have chosen their targeted future home to be two-storey detached house (villa) with a total site area between 400 m² and 600 m². It consists of a master bedroom, three regular bedrooms, four bathrooms and toilets, two guestrooms (one each for men and women), two kitchens (one internal and the other is external), a living room, a dining room, an office, a multi-purpose room, a laundry and a storage. Some of the main features of the designed home are highlighted in Table 2 and Fig. 2.

The house designed in this work was modelled in the five climatic zones of Saudi Arabia. Since the electricity performance of buildings is influenced by their orientation, the modelled home was simulated at each location for eight different orientations covering the 360° compass range in steps of 45°. The orientation was optimized on the basis of the minimum annual household electricity requirement. Generally, the orientation of buildings is found to influence the electricity performance of dwellings by less than 0.5%. The optimum orientation was found to be the North similar to Fig. 2 for all locations except for Jeddah where it is found to be the East. The simulation results revealed that Dhahran and Jeddah are the most challenging locations in terms of annual electricity demand and the peak power demand due to their higher air temperature and relative humidity especially during the summer months (see Fig. 3 and Fig. 4). The simulation results revealed that the annual electricity demand for houses in Dhahran, Guriat, Riyadh, Jeddah, and Khamis Mushait is 129 kWh/m², 91 kWh/m², 112 kWh/m², 165 kWh/m², and 60 kWh/m², respectively.

TABLE 2. KEY FEATURES OF THE STUDY MODEL

House Feature	Description
Ground Floor Area	214.1 m²
First Floor Area	214.1 m²
Total Glazed Area	55.2 m²
Total External Wall Area	446.8 m²
Total Roof Area	228.1 m²
Lettable Area	76%
Circulation Area	24%
Window-to-wall ratio (WWR)	10%
Building Envelope Systems	
External Wall	(25mm Stucco+75mm Concrete Block+50mm Polystyrene+75mm Concrete Block+25mm Stucco) U-Value= 0.49 W/m².K
Internal Wall	(25mm Stucco+100mm Concrete Block+25mm Stucco) U-Value= 2.50 W/m².K
Roof	(25mm Terrazo+25mm Mortar+ 4mm Bitumen Layer+150mm Cast Concrete+200mm Concrete Block+25mm Stucco +15mm Gypsum Board) U-Value= 1.74 W/m².K
Ceiling	(20mm Granite+25mm Mortar+150mm Cast Concrete+200mm Concrete Block+25mm Stucco+15mm Gypsum Board) U-Value= 1.57 W/m².K
Ground Floor	(15mm Granite+25mm Mortar+100mm Cast Concrete) U-Value= 0.48 W/m².K
Windows	Aluminium Window with thermal break, U-Value= 3.43 W/m².K
External Doors	External Door (Aluminium Door- Aluminium frame with thermal break) U-Value= 6.42 W/m².K
Internal Doors	Internal Door (40mm Wooden door) U-Value= 2.60 W/m².K
Building Services Systems	
Air-Conditionning System	Min. Flow rate = 8 l/s/person for Mini Split System
Lighting System	Tungsten Halogen Lamps at (Bathrooms, Toilets, and Kitchens), and Compact Fluorescent Lamps at (All other Spaces)
Domestic Hot Water	190 Litter (90% Delivery Efficiency)
Auxiliary ventilation	(Kitchen =50 l/s, Toilets and bathrooms = 25 l/s)
Kitchen Appliances	Maximum Power Consumption = 30 W/ m² [20]
Living Zone Appliances	Maximum Power Consumption = 7 W/ m² [20]
Sleeping Zone Appliances	Maximum Power Consumption = 7 W/ m² [20]
Guest Zone Appliances	Maximum Power Consumption = 5 W/ m² [20]
Heating Simulation set-point	20.0 °C
Cooling Simulation set-point	24.0 °C

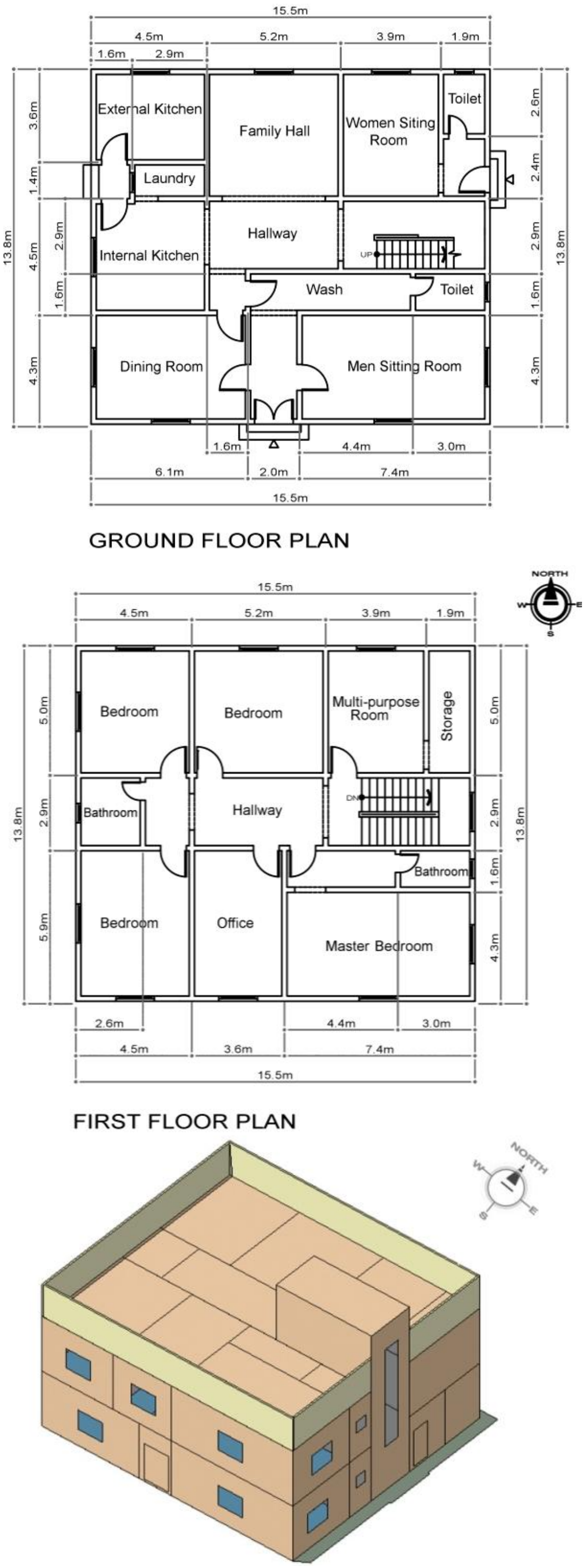

Fig. 2. MODEL AND FLOOR PLANS FOR THE STUDY MODEL.

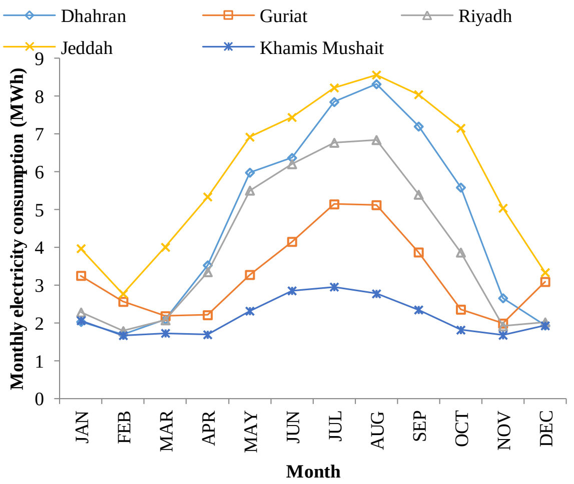

Fig. 3. MONTHLY ELECTRICITY CONSUMPTION FOR THE STUDY MODEL BASED UPON OPTIMUM ORIENTATION IN THE FIVE CLIMATIC ZONES.

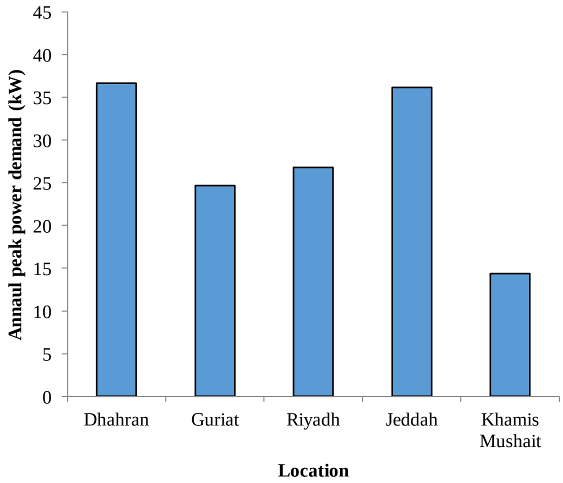

Fig. 4. ANNUAL PEAK POWER DEMAND FOR THE STUDY MODEL BASED UPON OPTIMUM ORIENTATION IN THE FIVE CLIMATIC ZONES.

IV. RESULTS AND DISCUSSION

Before undertaking the investigation, the electricity performance of study model was compared with measured electricity values gathered from 20 dwellings that were similar to the study model in terms of air-conditioning (A/C) system, thermal insulation, type of windows, and energy source for cooking. The electricity data for these homes, located in the Dhahran Zone, was obtained from their monthly electricity bills for period between January 2012 and December 2012. Dhahran is a main representative city in the Eastern Province which has the highest maximum temperature among all climatic zones (see Table 1). 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 electricity demand as indicated in Fig. 3 and Fig. 4. The annual electricity consumption for the study model in Dhahran was found to be 129 kWh/m², which is in close proximity with the average for the 20 dwellings in same location - the mean and median electricity consumption values for the survey dwellings are 147 kWh/m² and 137 kWh/m² respectively. In terms of the monthly electricity consumption, the findings of this study have shown a clear correlation between the values for the base house and the surveyed dwellings in most of the months (see Fig. 5). However, the monthly electricity consumption for the surveyed dwellings is a bit higher during the cold season and this could because the winter in 2012 was colder in comparison to extracted weather file from Meteonorm 5.1 [21].

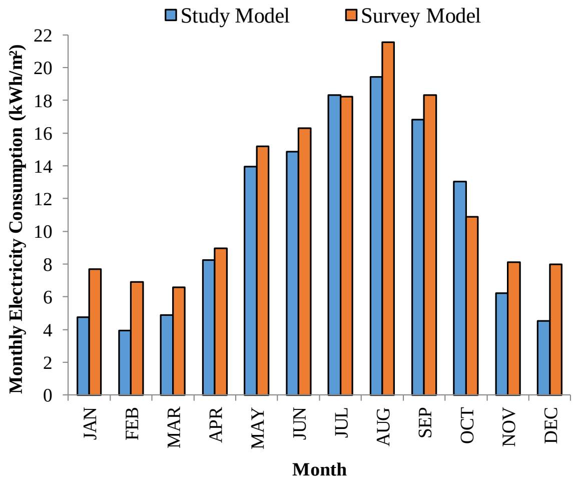

Fig. 5. MONTHLY ELECTRICITY CONSUMPTION FOR THE STUDY MODEL AND SURVEY MODEL.

The total demand for electricity can be calculated by breaking down the consumption at each individual location. In the present work, a breakdown analysis of the consumption reveals that the electricity demand mainly comes from the heating, ventilation and air-conditioning (HVAC) system, domestic equipment and lights in all locations (see Table 3). Domestic hot water (DHW) observed to be the least demanding parameter in all locations.

TABLE 3. ELECTRICITY CONSUMPTION BREAKDOWN OF KEY BUILDING SERVICES SYSTEMS.

System	Dhahran		Guriat		Riyadh		Jeddah		Khamis Mushait	
	Rank	*%*	*Rank*	*%*	*Rank*	*%*	*Rank*	*%*	*Rank*	*%*
HVAC	1	64	1	49	1	58	1	72	2	23
Equipment	2	24	2	34	2	28	2	19	1	52
Lights	3	10	3	14	3	12	3	8	3	21
DHW	4	2	4	3	4	2	4	1	4	4

Since HVAC system is the predominant consumer of electricity in most of the studied locations, the contributors to the HVAC system were broken down into its individual elements. This further investigation revealed that though results may vary from location to location, the important factors for all locations are internal gain, solar gain, external conduction gain, and infiltration gain (see Table 4).

TABLE 4. BREAKDOWN OF FACTORS CONTRIBUTING TO THE HVAC LOAD.

Contributor	Dhahran		Guriat		Riyadh		Jeddah		Khamis Mushait	
	Rank	*%*	*Rank*	*%*	*Rank*	*%*	*Rank*	*%*	*Rank*	*%*
Internal gain	1	47.7	1	47.0	1	48.6	1	36.7	1	42.4
Solar gain	3	15.1	3	15.2	3	16.6	4	12.6	3	15.3
External conduction gain	2	26.3	4	10.1	2	21.5	2	27.6	4	13.4
Internal conduction gain	5	2.2	7	1.2	5	2.4	7	1.1	8	0.3
Auxiliary ventilation gain	7	0.7	5	3.6	6	2.0	6	1.7	5	4.3
Natural ventilation gain	6	1.1	6	1.3	7	0.8	5	2.3	6	1.3
Infiltration gain	4	6.7	2	21.2	4	8.0	3	18.0	2	22.5
Free cooling ventilation gain	8	0.3	8	0.3	8	0.2	8	0.2	7	0.5

The internal gain usually consists of lighting gain, equipment gain, and people gain. In this study the half of the total internal gain comes from people (see Fig. 6).

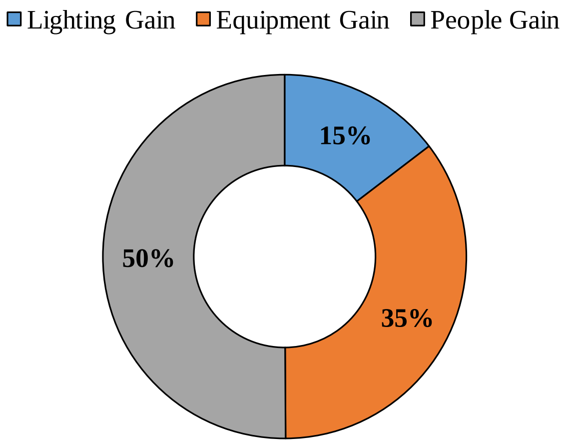

Fig. 6. BREAKDOWN OF INTERNAL GAINS FOR THE STUDY MODEL IN ALL LOCATIONS.

External conduction takes place through the building envelope comprising of walls, windows, doors, ground floor and roof. The analysis indicated that the impact of each component on the external conduction gain differs from location to location (see Table 5). Walls, window glazing and roof are observed to be the most influencing external conductors on the HVAC loads.

TABLE 5. BREAKDOWN OF EXTERNAL CONDUCTION GAINS.

External conductor	Dhahran		Guriat		Riyadh		Jeddah		Khamis Mushait	
	Rank	*%*	*Rank*	*%*	*Rank*	*%*	*Rank*	*%*	*Rank*	*%*
External walls	2	25.8	3	20.2	2	23.0	2	25.0	4	14.1
External glazing	4	0.8	1	41.3	5	1.8	3	4.6	1	34.2
External doors	3	4.1	5	0.3	3	4.3	4	3.3	5	0.5
Ground floor	5	0.2	2	34.3	4	1.9	5	2.3	2	29.4
Roof	1	69.1	4	3.8	1	68.9	1	64.9	3	21.8

V. CONCLUSION

Saudi residential buildings have a substantial representation in the national energy consumption, accounting for over 50% of the total electricity use, and are experiencing a fast growth to meet the demands of the burgeoning population. Thus, it is critical to improve their energy-efficiency levels. However, in order to achieve this improvement, a systemic investigation of electricity demand is essential to identify areas which need to be focused on in terms of energy conservation. The present study suggests that the household electricity demand comes mostly from the HVAC systems, domestic equipment and lights. It also suggests that the domestic equipment are not only responsible of a significant part of the household electricity demand through the direct use by occupants but also responsible of another part of it as a contributor to the HVAC load. Nevertheless, it is crucial to understand that the factors affecting HVAC system are differing from a climatic zone to another. For instance, while roof and walls are the highest external conducting contributors on the HVAC load in Dhahran, Riyadh and Jeddah; external glazing and ground floor are the highest contributors in Guriat and Khamis Mushait. In order to apply energy conservation concepts, the potential for reducing the electricity demand should be investigated according to the the suggested parameters ranks and climatic zone in this study. Subsequently, various energy-conservation measures can be proposed and applied in a cost-effective way to increase the level of energy-efficiency in Saudi residential buildings.

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