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Reducing High Energy Demand Associated with Air-Conditioning Needs in Saudi Arabia

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Abstract: Electricity consumption in the Kingdom of Saudi Arabia (KSA) has grown at an annual rate of about 7% as a result of population and economic growth. The consumption of the residential sector accounts for over 50% of the total energy generation. Moreover, the energy consumption of air-conditioning (AC) systems has become 70% of residential buildings' total electricity consumption in the summer months, leading to a high peak electricity demand. This study investigates solutions that will tackle the problem of high energy demand associated with KSA's air-conditioning needs in residential buildings. To reduce the AC energy consumption in the residential sector, we propose the use of smart control in the thermostat settings. Smart control can be utilized by (i) scheduling and advance control of the operation of AC systems and (ii) remotely setting the thermostats appropriately by the utilities. In this study, we model typical residential buildings and, crucially, occupancy behavior based on behavioral data obtained through a survey. The potential impacts in terms of achievable electricity savings of different AC operation modes for residential houses of Riyadh city are presented. The results from our computer simulations show that the solutions intended to reduce energy consumption effectively, particularly in the advance mode of operation, resulted in a 30% to 40% increase in total annual energy savings.

Keywords: air-conditioning; peak demand; renewable energy; Saudi Arabia; occupancy behavior

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1. Introduction

The Kingdom of Saudi Arabia (KSA) has a desert climate that is characterized by high heat during the day and a temperature drop at night; the heat rapidly increases after sunrise and stays so until sunset. In a year, there are mainly two seasons: winter and summer. In summer, the average temperature is about 45 °C, but the ambient air temperatures could reach up to 50 °C [1].

The electricity sector in KSA is faced with the great challenge of meeting the increasing electricity demand. Over 50% of the Kingdom's total electricity production is consumed by the residential sector. Moreover, over the last few decades, the growth in energy consumption is approximately 7% annually, and 60% to 70% of the energy consumed by residential buildings is due to the air-conditioning systems during the summer months [2,3]. Figures 1 and 2 show KSA's typical daily electricity load curve during the summer and winter, respectively [4]. As can be observed in Figure 1, the peak demand for electric power in KSA occurs midday, between 11:00 and 17:00 (from May to September). The surges during that period of the day in summer is non-existent in the winter (e.g., the peak time in winter is 14:00–15:00).

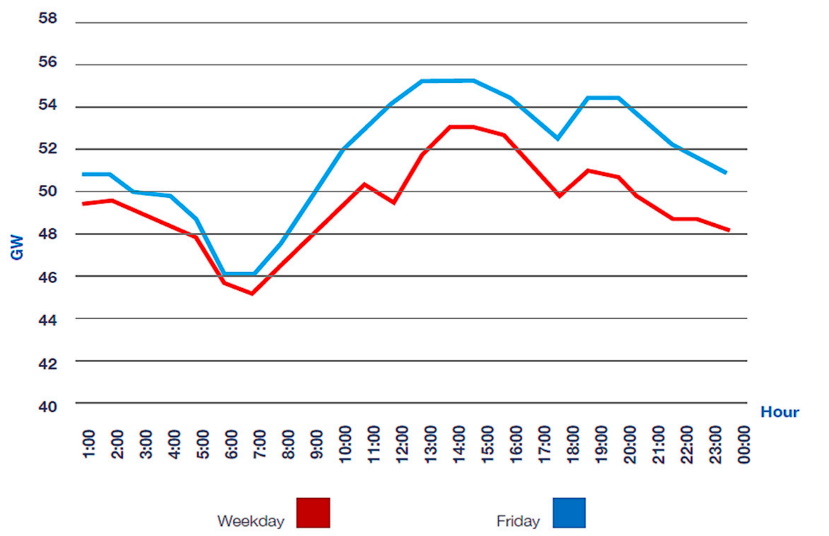


Figure 1. Kingdom of Saudi Arabia's (KSA) typical daily electricity load curve during summer [4].

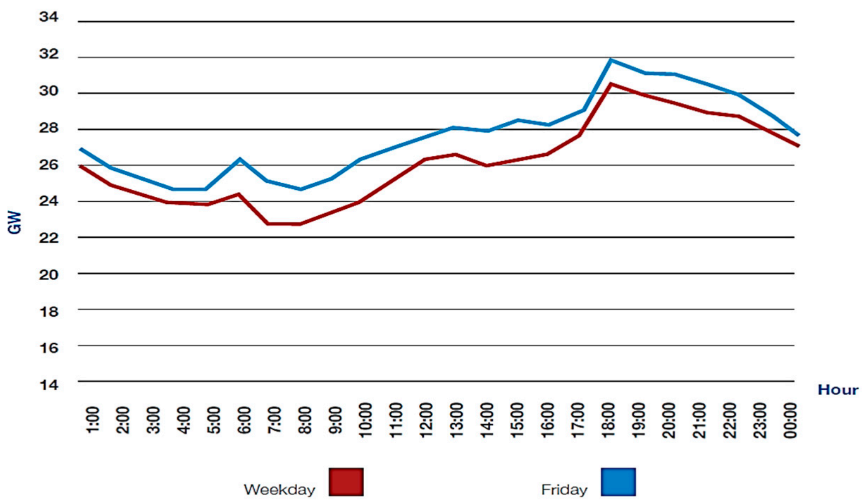


Figure 2. KSA's typical daily electricity load curve during winter [4].

Comparing the two figures further, the demands at 13:00 in the summer and winter during the weekdays are 52 GW and 26.5 GW, respectively; during the weekend, 56 GW and 28 GW, respectively. It can also be noticed that ACs are used day and night during the summer (at 19:00 in the night on the weekday, the demands are 51 GW and 30 GW in summer and winter, respectively). Thus, to meet the peak demand, an additional generation capacity of 2 to 5 GW is added each year to meet the country's growing electricity demands (ECRA, 2015), as the current committed capacity will not be sufficient to meet the projected demand, according to King Abdullah City for Atomic and Renewable Energy (KACARE).

Around 70% of KSA's buildings are not thermally insulated, according to Saudi Energy Efficiency Centre (SEEC) [5], which is a major cause of the high electricity consumption. Consequently, a huge part of air-conditioning loads is the heat transmission through the walls of buildings and roofs [6]. Another huge contributor to the high electricity consumption is occupant behavior. For instance, many of the customers in KSA leave their air-conditioning units to run non-stop throughout the summer months [7,8]. Over 73% of households in KSA turn on their air-conditioning systems from between 10 and 24h on a typical day during the summer months [9]. A significant amount of energy saving can be achieved even by a small increase of AC thermostat settings, e.g., 1 °C or 2 °C [10,11]. These savings are particularly important and desirable during the peak duration of electricity demands.

The setting of the thermostats to one value throughout the summer and to another value throughout the winter (with the two values determined by averaging the daily optimal values) can significantly reduce air-conditioning loads and increase energy savings (which could reach billions of dollars in cost reduction at national level [12]) while still achieving the desirable thermal-comfort for occupants [6].

This paper will therefore investigate some solutions to the problem of KSA's high-energy demand associated with air-conditioning needs in residential building. It is clear that improvements in this area will effectively encourage the reduced operation of air-conditioning units and will achieve savings in the total energy consumption of buildings. These savings are particularly important during the peak duration of electricity demand in the summer months. Typical residential buildings of KSA will therefore be modelled and simulations will be carried out in order to understand the different solutions, particularly with regard to ACs that can effectively reduce the energy consumption of air-conditioning units. In addition, we examine the potential impacts of the achievable electricity savings in each mode. Representative models describing occupancy behavior of KSA's residential buildings are not available, as far as the author is aware. These models are needed for computer simulation of the energy consumption of KSA's residential buildings in order to propose solutions that will make energy savings achievable. In this respect, a survey is carried out as part of this study in order to understand occupancy behavior times, in which rooms are occupied and electricity is being used. To the author's knowledge, this is the first attempt to describe KSA's occupancy behavior of residents. The insights gained from the survey will be used for the computer simulation of residential buildings' energy performance, which will further the understanding of possible energy savings if AC systems are used in a more energy efficient manner. Thus, in addition to using data of the typical house types and their actual dimensions and building materials, the computer simulation will take into account the typical behavior of occupants of residential buildings in Riyadh city, making use of behavioral data obtained through the survey that was carried out.

2. Literature Review

By reducing the energy usage of AC systems, a reduction in the consumption of energy can be achieved. To accomplish this energy reduction, strategies can be modeled from past studies, such as [13]: retrofitting existing AC systems; developing new AC systems; manufacturing designs, such as increasing the number of condenser rows can lead to a higher Energy Efficiency Ratio (EER) in KSA [14]; and using air-conditioning modes that are energy efficient (a suitable operational strategy of AC could reduce approximately 23% of KSA's energy consumption [15,16]). These strategies are further elaborated upon in the ensuing paragraphs.

The Kingdom's residential buildings have rapidly expanded in growth despite the fact that no serious consideration of the energy efficiency of these buildings has been respected. Consequently, the architectural design of the buildings encourages excessive energy consumption of AC systems. Moreover, although the shape of the buildings unfavorably affects solar heat gain, the building still lacks proper shading strategies [9,17]. The construction of climate-responsive, energy efficient, and environmentally friendly building design technologies have recently been considered [18,19]. Retrofitting insulation to these buildings can be suggested to tackle this problem, but that would require major and laborious work and would take many years to retrofit existing buildings. However, measures for proper and better insulation could be setup, for example, improvements in the architectural design for better energy efficiency in future residential building projects.

The behavior of occupants of a building is one of the four most important factors influencing the building's energy consumption. In particular, the building's heat gains and the occupants' comfort requirements. The other three factors being the thermal control equipment installed in the building (i.e., heating, ventilation, air-conditioning system, and hot-water heating system), the building's physical properties (i.e., orientation and location, as well as the buildings outdoor environment, such as temperature and solar radiation) [20]. By far, the most difficult factor to model is occupancy behavior, largely because humans, by their very nature, are unpredictable [21].The presence of humans within a building initiates other activities, such as the emission of water vapor and carbon dioxide or the use of electrical appliances for lighting, heating, or cooling, and so on. These variables affect the indoor behavior of the building [22]. Importantly, humans adjust the appliances and/or their surroundings in order to optimize their comfort (such as opening the windows, turning ON the ACs, or adjusting the lighting).

The availability of occupancy information allows the prediction of occupancy pattern, which is very important for scheduling climate control for the building [23]. The ability to predict both short-term vacancies, such as intermittently entering and leaving a room or home, moving from one room in a house to another, or leaving the house for work, and long-term vacancies, such as business trips, illnesses, and holidays, can provide meaningful energy savings [24]. It is particularly difficult to predict the occupancy behavior of an individual building, but trends of behavior can be studied for a group of buildings in order to model long-term behavior [20]. In relation to KSA, none of the studies carried out so far have dealt with customers daily electricity consumption pattern in residential buildings. This information is crucial to understanding the occupancy behaviors that are critical for scheduling and controlling the buildings' climate [23]. Moreover, simulation results that can be produced using building models and simulation software can only be as good as the ability of such models to accurately predict occupancy behavior of the buildings [22]. For this paper, a survey has been undertaken to investigate some of the behavioral factors causing high-energy consumption in Saudi Arabia's domestic buildings. The adjustment of consumer energy demands—especially when considering customer behavioral changes as a result of education or financial incentives—is often referred to as Demand Side Management (DSM). Through DSM, customers are encouraged to use less energy during peak hours, which is often achieved by moving the time in which energy is used by customers to off-peak times, such as early morning, evening, or weekends. In order to achieve DSM in KSA, the use of thermal energy storage systems that will store energy for use by AC systems during peak periods has been proposed in [25,26]. Through the analysis of the simulation results regarding residential buildings equipped with thermal energy storage systems and of the historic electricity demand data given in [25], promising potential of the technology can be observed. However, the lack of efficiency in the production of ice during the day when electricity demand is at the peak limits the capability of the technology.

Furthermore, Demand Response (DR) is a technology that enables an economic rationing system through the adjustment of consumer energy consumption by using electric utilities to match consumer demands with the energy supply. To achieve DR, electricity customers are offered low prices for electricity during off-peak hours and a high price during peak periods. Studies have shown that DR programs are capable of reducing the system peak by up to about 9% [27–29]. Examples of the price-based DR programs are the real-time price (RTP), the critical-peak price (CPP), and the time-of-use (ToU) programs. DR has been proposed for KSA recently (see [30]) as a way of managing energy consumption. Moreover, the impact of the ToU pricing option for customers in KSA was studied in [31], where it was observed that with ToU, the utilities were able to realize higher profits from the residential sector and effectively reduce the sector's high energy demand.

When extending DR to residential sector, the challenges include finding the optimum schedule and the ICT infrastructure that can be deployed to actualize DR [32–34], as well as managing the conflicting objectives of minimizing energy cost for the customer [32]. Some of the issues with DR are customer inconvenience and responsiveness for different DR programs [35] and the effect of different tariffs on the level of responsiveness [36]. Importantly, it has been shown that a large number of customers do not respond to price by changing their consumption behavior. This factor must be considered when designing DR schemes [32,35]. In addition, certain types of domestic appliances, such as air-conditioning systems, are better candidates than others when providing DR [36]. Because it is not practical that all customers respond simultaneously to take advantage of DR, it has been suggested that as little as 5% of customers is enough to curtail electricity market price and as much as 20% of all customers can account for 80% of electricity price response [37].

In this paper, three modes of air-conditioning systems are proposed as solutions to mitigate the challenges of KSA's electricity demand during the peak period of summer. The first two modes that will be discussed fall into the DSM category of electricity management strategy, while the third mode of operation falls into the DR category.

3. Energy Use and Customer Behavior Survey

Developing a representative model of occupancy behavior for computer simulation and/or for practical planning and design of buildings, in relation to air-conditioning systems, is important but challenging, due to the lack of reliable data that covers a representative range of human behavior [38,39]. In this paper, a survey has been undertaken to investigate some of the behavioral factors causing high-energy consumption in Saudi Arabia's domestic buildings. A survey questionnaire was designed, piloted, and distributed to people of different gender and regions across Saudi Arabia in order to obtain information related to building design, occupants' behavior with regard to electricity use, perception on renewable energy, and so on.

Besides the online survey, interviews were carried out with several residences from two regions in KSA. This was done to investigate these residencies behaviors regarding energy consumption, particularly their AC use. Actual readings of household-level electricity consumption from the different types of KSA housing units were measured using applications available on customer mobiles. This could also provide an overview over the previous three years of consumption.

The questionnaire was divided into the following four sections: (1) A section investigating accommodation data, such as the number of guest rooms, bedrooms, and bathrooms, as well as accommodation types; (2) A section investigating the high electricity consumption of home appliances by type and number; (3) A section investigating the occupants' behavior regarding times rooms were occupied and usage of high electricity consumption appliances; (4) A section exploring people's perceptions of renewable energy in homes.

Both English and Arabic languages were used in the questionnaire. The questionnaire of the survey was distributed to participants from the whole kingdom via email, WhatsApp, and Twitter. The online survey dissemination system was utilized because it was easier, faster, and less expensive than a printed survey [40,41]. The questionnaire was initially sent through relatives, friends, colleagues, and other acquaintances who further recruited additional acquaintances from their wide networks, such as friends and colleagues [42]. Consequently, the sample includes various respondents who came from all the regions of KSA. It is reasonable to assume that the survey has found the more common patterns of room occupancy and AC use, which are taken forward into the simulation studies. The detailed questionnaire is given in the Appendix A. In general, the questionnaire reached 451 participants; 383 of these completed and returned the forms. The demography of the respondents (i.e., family size, number of bedrooms, guestrooms, and AC units in the household) is given in Figure 3.

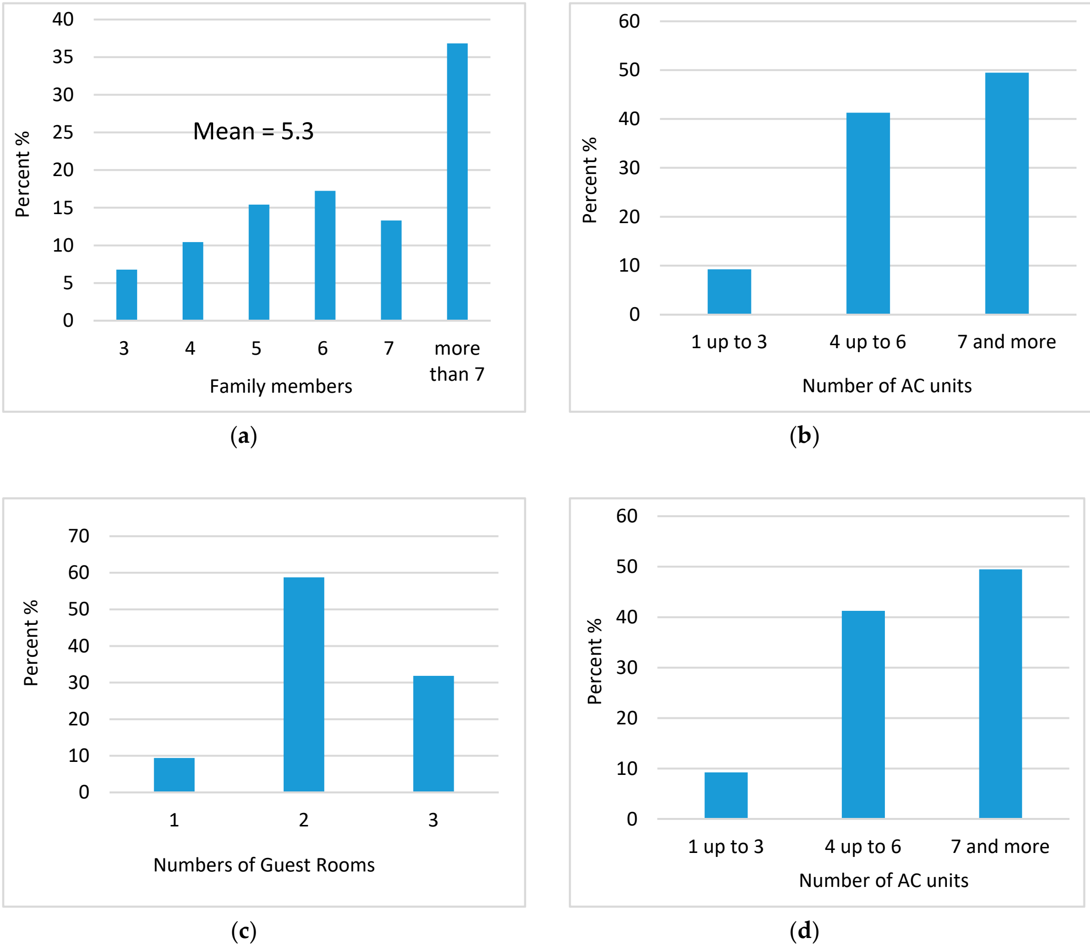


Figure 3. Demography of survey respondents: (**a**) Family members; (**b**) Number of bedrooms; (**c**) Number of guest rooms; (**d**) Number of AC units.

Saudi Arabian culture features extended families living together in large houses, referred to as villas; affluent families often own villas. The less affluent families often reside in individual houses that are referred to as traditional houses. The rapid growth in KSA's population required quick construction of cheap accommodation in the form of several flats (apartments) within individual buildings (or apartment blocks). Detached single- or two-story houses were also built with rapid construction. In some cases, the two-storys were used as two separate floors (one floor on the top and the other at the bottom). Regardless of whether a residential building is a villa, a traditional house, a flat, or a single- or two-story house, the rooms were large; the average property in KSA is more spacious than its equivalent in Western Europe. Therefore, from the survey, of the total number of respondents, 40% live in villas, 41% live in flats, and fewer than 20% live in traditional houses. Overall, 90% of the respondents have more than one guest room (unlike in the English culture, where a guest room often denotes a room within the house where guests are presented to sleep, a guest room in the Saudi culture is more or less a reception room where guests are received and served; these rooms are typically larger than bedrooms and, as custom, guests do not normally go beyond these guest rooms). Furthermore, 58% of respondents have two guest rooms and 33% have three guest rooms. Also, nearly 50% of respondents have seven or more AC units at their homes.

The bar charts in Figure 4 provide information on the household behavior in KSA and it is clear that the behavior of AC users in KSA offers potential for substantial energy savings.

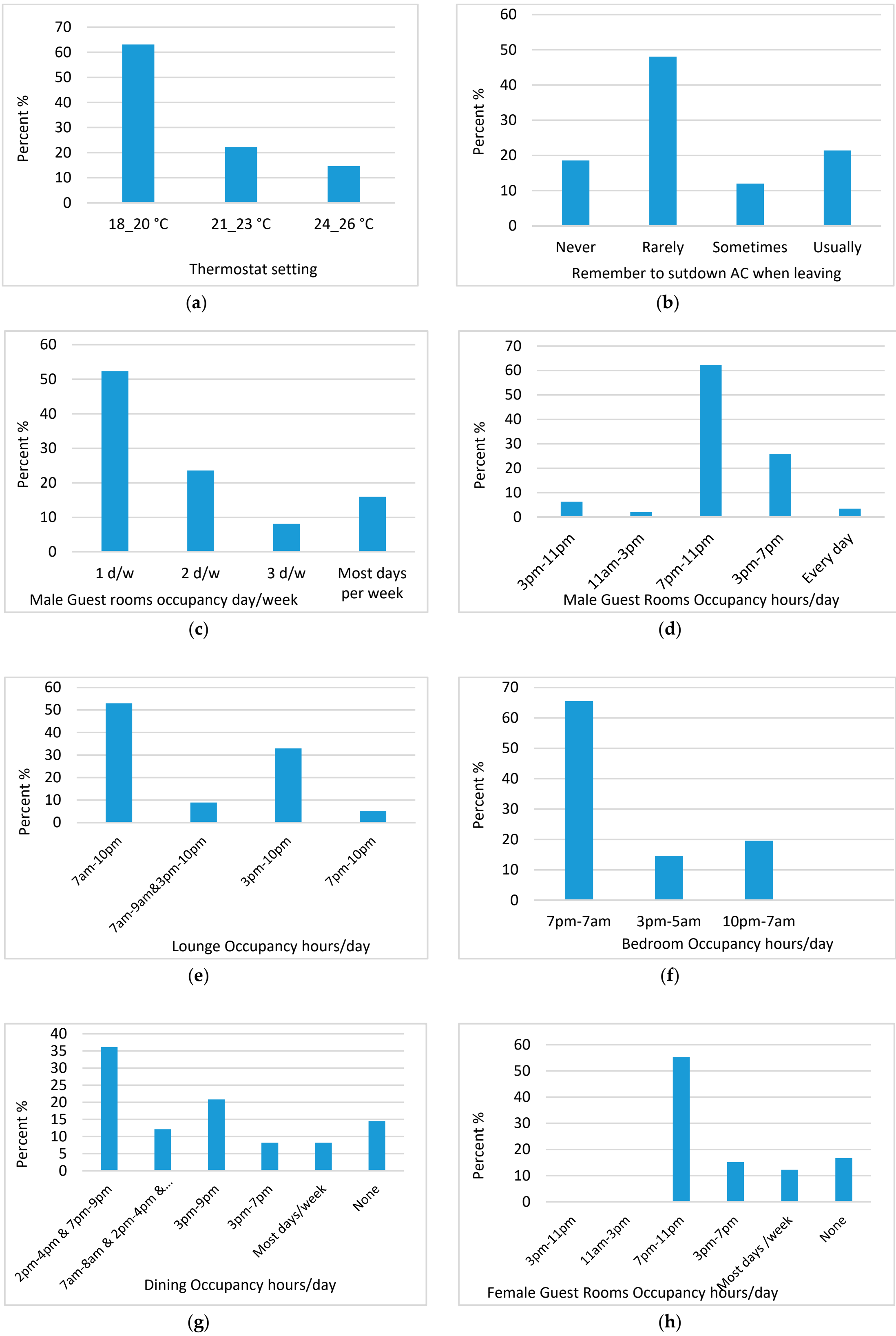


Figure 4. KSA's household occupancy behavior: (**a**) AC thermostat setting; (**b**) Remember to shutdown AC when leaving; (**c**) Male guest room occupancy day/week; (**d**) Male guest room occupancy hours/day; (**e**) Lounge occupancy hours/day; (**f**) Bedrooms occupancy hours/day; (**g**) Dining room occupancy hours/day; (**h**) Female guest room occupancy hours/day.

Some highlights from these results include:

- The guest rooms are occupied mostly one day in a week.
- The main bedrooms of most respondents are occupied between 7:00 pm and 7:00 am the following morning.
- 51% set their AC thermostats to between 18 °C and 20 °C, while 21% set it to between 21 °C and 23 °C.
- 66% rarely or never shut down their ACs during the summer months, compared to 22% that usually do. The remaining 12% fall between these two extremes.

4. Parameters of the Energy Consumption Computer Simulation

The DesignBuilder® software was developed by DesignBuilder Software Ltd, based at Stroud, Gloucestershire, United Kingdom. It is a popular and commercially-available software tool used for modelling and simulating energy efficient and comfortable building designs. It has been selected among others computer software tools, including DOE-2, EnergyPlus, TRNSYS, and ApacheSim for simulation in this study, because it has an easy-to-use interface. Furthermore, it has useful built-in features that facilitate energy performance comparisons, detailed modelling of Heating, Ventilation, and Air Conditioning (HVAC) systems, and natural ventilation, which enable optimization of renewable energy systems for buildings' energy performance improvements. It also provides a simulation of cooling/heating design calculations over any period of time, such as a day, a week, a season, or a year. In order to simulate the thermal performance of a house using the DesignBuilder® software, the model parameters must be defined. Model parameters describe the physical characteristics (including plan and geometry), installed equipment or appliances, building purpose and occupancy behavior, the geographical location and climate, and the nature of the surrounding environment, among others.

Characteristics of KSA residential buildings and construction materials are summarized as follows [43,44]:

- Cement-based hollow building blocks with a thickness of 15 cm or 20 cm and surface dimension of 40 × 20 cm^2.
- Residential building walls consist of three layers: the external cement plaster, the hollow brick (with different thickness sizes depending on whether they are inner or outer walls), and the interior cement plaster.

Table 1 shows the summary of other input data for the simulation software.

Table 1. Summary of the input data for simulation in DesignBuilder.

Lighting	Openings	HVAC	DHW*	Occupancy
• Luminous and louvered ceiling. Lighting is used with following properties: • Lighting energy = 0.4 W/m^2 • Radiant fraction = 0.37 • Visible fraction = 0.18	• Single glazing windows (6mm) • Glass Area = 1m^2 • Solar set-point conduction ratio = 1 • Position = Inside	• Split no fresh AC Air with COP= 2.2 • Based in electricity from grid	• DHW COP = 2.5 • Instantaneous hot water	• density of 0.2 people/m^2 • Metabolic • Activity= Light Manual Work • Metabolic factor= 0.9

* Domestic Hot Water.

There are four general types of residential housing units in KSA: a floor in two-story house (which shall be denoted as House 1 in this study), a traditional house (which shall be denoted as House 2 in this study), a villa, and a flat (or an apartment) [45]. According to KSA's General Authority of Statistics [45], there are 829,670 housing units in Riyadh city: 127,466 of House 1 type, 47,596 of House 2 type, 374,900 villas, and 279,708 flats; the average family size is 5.97. (Further details on the four groups of Riyadh's residential buildings are given in Table 2.) The occupants of these houses participated in the customer behavior survey presented in the previous section. Moreover, the construction materials, as well as the electricity bills, used in this study came from these houses. It is important to note that the hourly electricity consumption data for individual dwellings in KSA was not available. However, monthly consumption was taken and compared from at least two houses from each group due to the availability of the application on customers' mobiles; the previous three years consumption can also be explored through this application. This setup will enable the comparison and validation of the simulation results that will be presented. The plans and geometric descriptions of House 1, House 2, the villa, and the flat are given in Figures 5–8, respectively.

Table 2. Details of the single floor house, the Villa, and the Flat.

Building Typology	Building's Name	No. of Floors	Area m^2	No of Occupants
A floor in two-story	House 1	1	177.69	4 adult + 3 children
Traditional House	House 2	1	171.82	2 adult + 4 children
Villa	Villa	3	279.72	2 adult + 5 children
Apartment	Flat	1	102	2 adult + 3 children

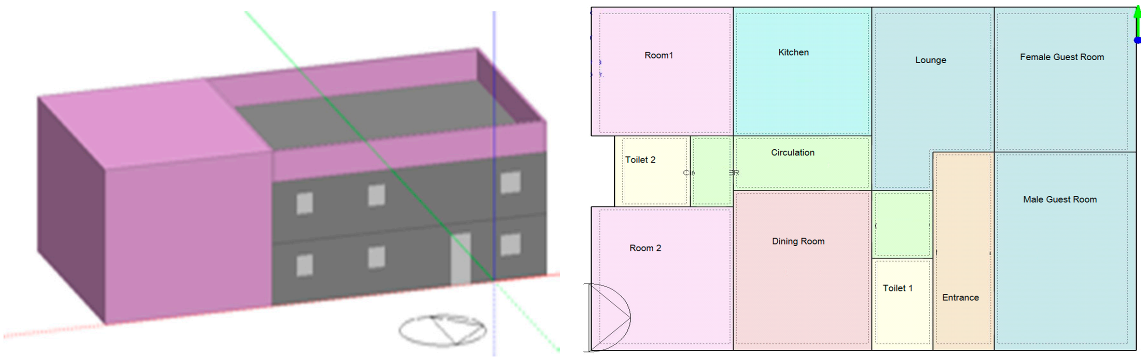


Figure 5. The plan and geometric description of House 1.

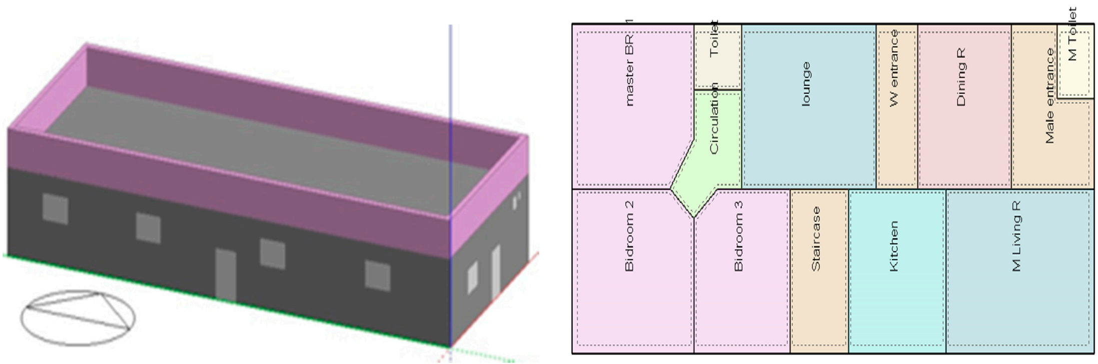


Figure 6. The plan and geometric description of House 2.

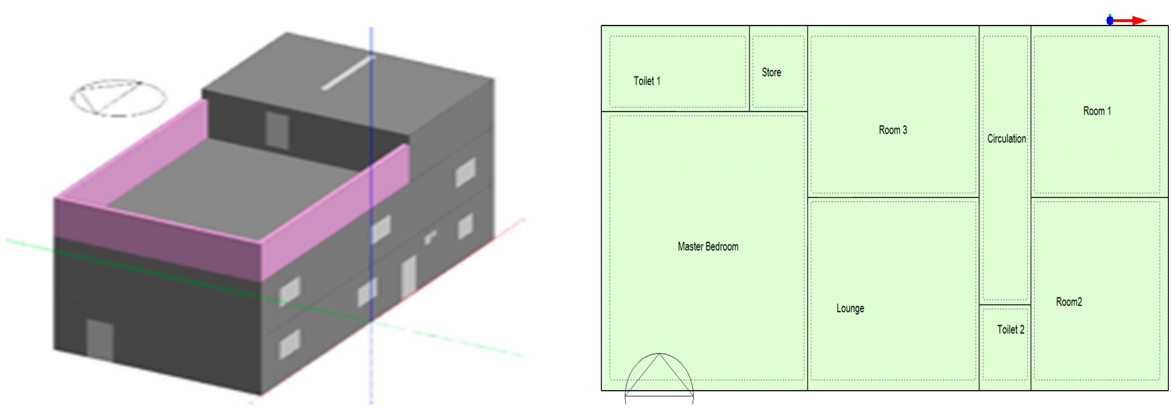


Figure 7. The plan and geometric description of Villa.

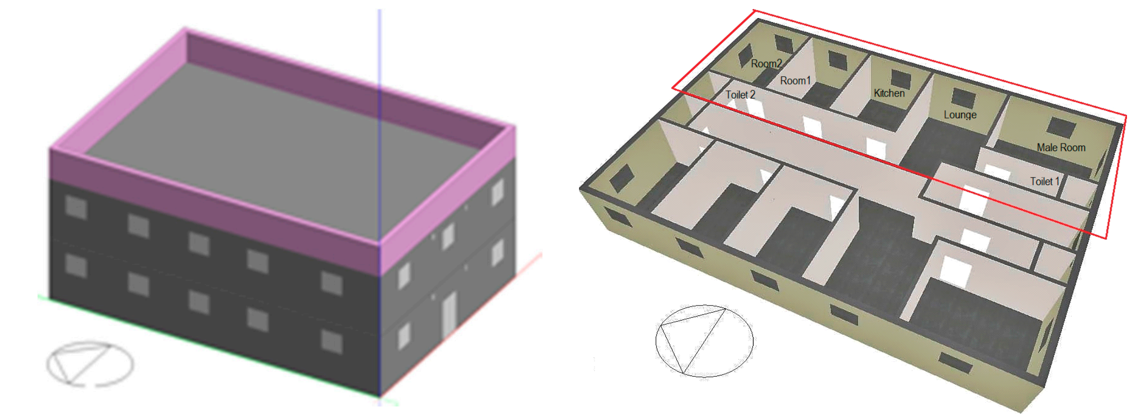


Figure 8. The plan and geometric description of the flat.

5. Methodology

This study used a simulation-based methodology, as it allowed for the simulation of different AC control schemes. Moreover, this approach allowed us to focus on many schemes at once, without the cost of purchasing equipment and sensors, and without the setup time of different testing conditions, which would have been necessary if an experimental approach had been considered. In order to simulate the thermal performance of a house, the model had to be defined. It describes the physical characteristics (including plan and geometry), installed equipment or appliances, building purpose and occupancy behavior, the geographical location and climate, and the nature of the surrounding environment, among others.

Despite the benefits and the progress made in the development of simulation software capable of modelling complex building systems and their environments, computer-based simulations are not without their disadvantages, which include the following [46,47]:

- Not all simulation data and parameters may be known or fully anticipated at the initial stage of the simulation, i.e., introducing uncertainties and/or risk factors in the model.
- The number of input parameters for obtaining a model that will be suitable for simulation can be very large. Therefore, a good calibration technique is important to obtain useful results.

The following steps outline the procedure adopted for carrying out the computer simulation in this study:

Step 1: The Selection of Representative Buildings from a Group of Buildings

In this step, we chose the set of buildings described above, which represented the majority of residential buildings in KSA (Riyadh, in particular).

Step 2: The Definition of the Buildings' Geometrical Parameters

In this step, the geometry of the buildings was defined based on physical visits, interviews, and surveys. The geometry was described in terms of room size (i.e., main rooms, guest rooms, kitchen, toilets, and so on) and the dimensions of the openings (i.e., doors and windows).

Step 3: Construction Materials (Thermal and Physical Characteristics)

This step examined the construction materials and properties of the houses, such as the materials for the external walls, internal walls, roofs, other parts of the buildings' envelopes, the shading, the glazing etc.

Step 4: Energy Consumption Profile for the Building Models

This step defined the results obtained from the survey, specifically regarding energy consumption and occupants' behavior, including their activities and schedules in each room in relation to electricity appliances usage, and, importantly, customer behavior in relation the usage of air-conditioning systems. In addition, details regarding the numbers, types, and AC operational strategies are provided.

Step 5: Constructing the Models in DesignBuilder

This involves creating models of the various houses using the DesignBuilder software tool. Modelling largely involves defining the model parameters, which we obtained from the previous steps, to the software tool. The defined model parameters includes the location (e.g., longitude and latitude), the orientation of the house, the climate condition (i.e., temperature and sun path), the house construction layout (i.e., details of the dimensions of external walls, roofs, internal partitions, floors, types of plasters, number of brick layers, etc.), the openings (i.e., glazing, shading, doors, and vents), the lighting (i.e., types and typical operation schedule), the HVAC system (i.e., their types, sizes, settings, and operation schedule), and the activities (i.e., schedules for occupancy), among others.

Step 6: Model Simulation and Thermostat Setting (Parameter) Discovery

The constructed models are used to simulate the performance of real KSA buildings. The results are then analyzed and used to adjust the model parameters in order to obtain a reasonable correlation between the actual (observed) energy consumption of the residential buildings and the predicted (simulated) energy consumption. In other words, the modelling, simulation, and analysis cycle is an iterative process. In particular, in order to ensure that the behavior of the models that is built with DesignBuilder reflects the actual behavior of the houses, the thermostat settings of the air-conditioning systems of the models have been adjusted to be consistent with the behavior survey. The monthly electricity consumption values obtained by simulation agrees with reasonable accuracy those on the actual electricity bills of the actual houses. The continuous operation, which a large number of people fall into according to the survey, will be used as a baseline for comparison among the following three proposed modes of AC operation.

- Mode 1: The Scheduled Mode

In this mode, in order to improve indoor comfort, the air-conditioning systems are programmed to turn on automatically an hour before the occupants are predicted to arrive home and to switch off automatically an hour after it is un-occupied. It is assumed that the houses are equipped with sensors that are able to detect occupancy and the occupancy activities are logged on a periodic basis so that improvement can be made on the scheduling program in the next or future cycle of air-conditioning operations. The unique feature of this mode is that the room temperature set points of the AC thermostats are fixed to the value in which most people fix their thermostat settings, according to the survey carried out in this research study (the fixed value is also backed up with the simulation carried out using Step 6).

- Mode 2: The Advanced Control Mode

The advanced control mode of the air-conditioning system operation has all the features of Mode 1 (the scheduled mode), except that here there is the added feature of changing the room temperature, i.e., changing the setting of a thermostat from a lower temperature value when the room is occupied to higher value when a room in the house is not occupied for a short duration, say, less than 10 minutes. Then, the advanced control mode can switch off the AC if the room remains unoccupied for a reasonable time, say 1 h. The additional feature in this mode is motivated by the need to save energy. The fact that a significant amount of energy savings can be achieved by even a small increase of thermostat settings—e.g., 1 °C or 2 °C [10,11]—has been largely ignored in practice, but this fact is important for this mode. Furthermore, this mode is in line with the electricity policies in KSA, which recommends that householders set the thermostats of their ACs to 24 °C (instead of lower values), as there is no significant difference between this thermostat setting and those of lower values to home occupiers' comfort [48].

● Mode 3: The Remote-Control Mode

The remote-control mode is significantly different from the previous two modes mentioned in that it is a Demand Response (DR) energy management approach. In this mode, the room temperature set points are remotely controlled by the utility company during the peak time. For example, ACs that are turned on in the subscribing customers' residences are remotely set to a higher value of 24 °C during peak times by the utility companies.

Step 7: Simulate the Final Models with Different Modes of Air-Conditioning Operation and Compare with the Baseline Models from Step 6

6. Results

Having defined the parameters of the house types to the DesignBuilder software, Figure 9 shows the actual reading and simulated results of an air-conditioning system operating on the continuous mode for a single floor in a two-story building (House 1). For the simulation results, two thermostat settings were tested; DesignBuilder was used to simulate House 1 with a thermostat setting of 18 °C and it was also used to simulate the house with a thermostat setting of 20 °C. As previously stated, 18 °C and 20 °C was the range that 51% of the survey respondents said they set their thermostat to during the summer months. From the results of the simulation in Figure 9, it is clear that a 20 °C setting is closer to the actual measured value that was actually taken for House 1 during this study. Thus, the value of 20 °C will be taken as the typical value of thermostat settings in subsequent simulations. Furthermore, it is important to note that the computer simulation was able to capture a significant increase in energy consumption from May to September, which is primarily due to the use of the AC during this period. Figure 10 shows the correlation plot of the two variables: the energy consumption obtained using the simulation and the energy consumption obtained by direct measurement. The value of 0.92 of the statistical coefficient of determination, R2, for the correlation plot indicates that the predictions from simulation highly fit the data from the actual measurement.

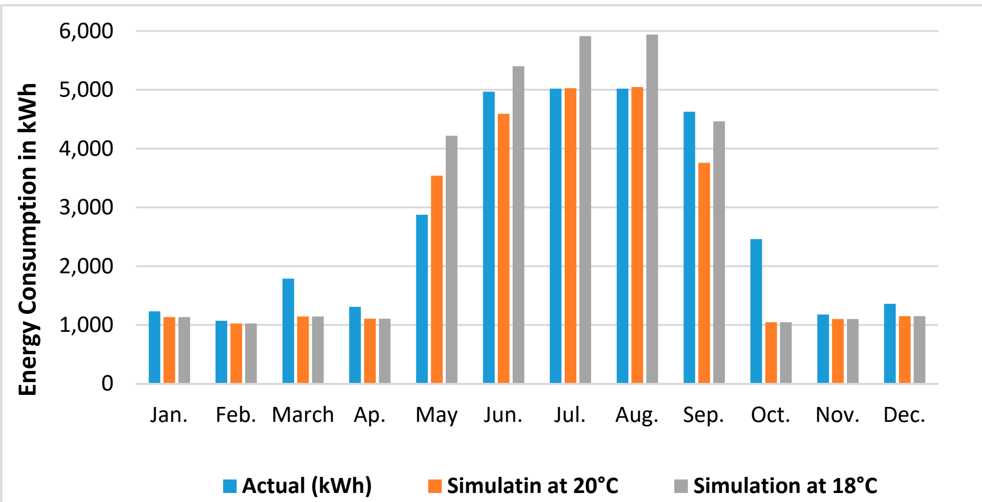


Figure 9. The actual reading and simulation results of the energy consumption of the air-conditioning (AC) with thermostat settings of 18 °C and 20 °C.

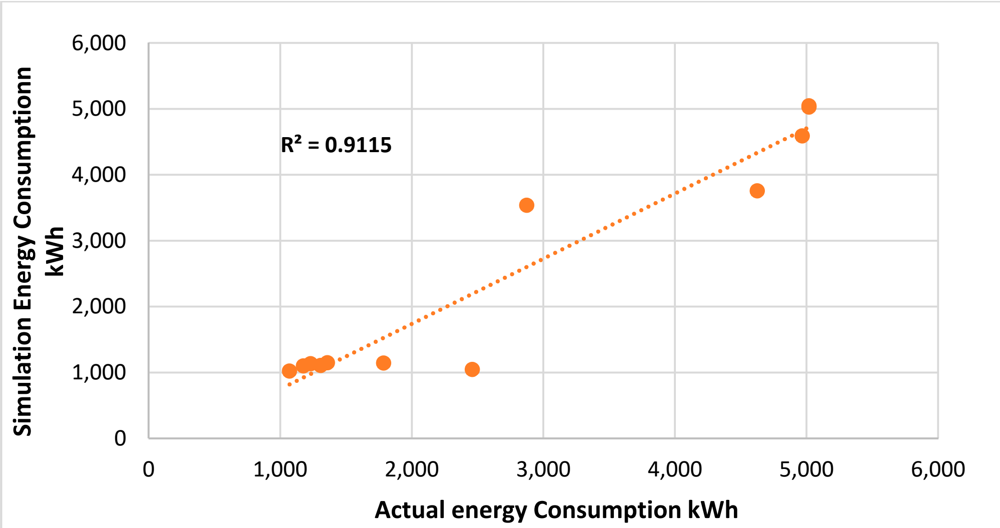


Figure 10. The correlation plot of the two variables: the energy consumption obtained using the simulation with the AC working on the continuous mode at a thermostat setting of 20 °C and by using the direct measurement obtained from the monthly bills.

The daily electricity profile for each simulated house showed an early afternoon peak, as seen in the national aggregated data. However, precise calibration was not possible because of the lack of hourly electricity consumption for the actual houses. Figure 11 shows the simulation of the hourly electricity consumption of House 1 on a typical day during the summer (4 July).

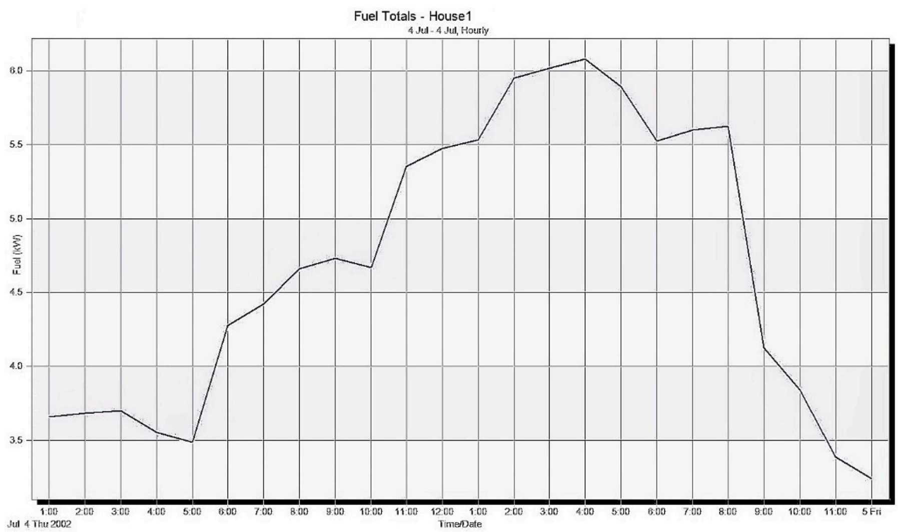


Figure 11. The simulation of electricity consumption of House 1 on a typical summer day (4 July) under the continuous mode.

To give an idea of how much energy consumption savings is possible, Figure 12 shows a comparison of the actual readings, as well as the results of the simulation, of a thermostat setting at 20 °C in a villa working on continuous mode, Mode 1 (scheduled mode), and Mode 2 (advanced control mode). For Mode 2, the thermostat settings for the AC are the same as Mode 1, except that the ACs' settings are changed from 20 °C to 24 °C, where it is supposed to be turned on and the room is unoccupied. The results show that Mode 2 has a minimum energy consumption, followed by Mode 1. The simulation of the continuous mode closely matches what was obtained from the measurement (actual household bill) for House 1.

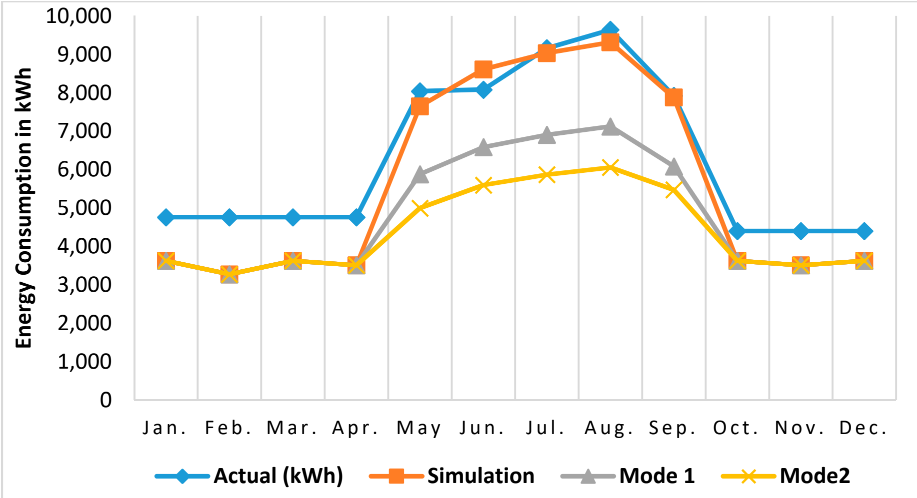
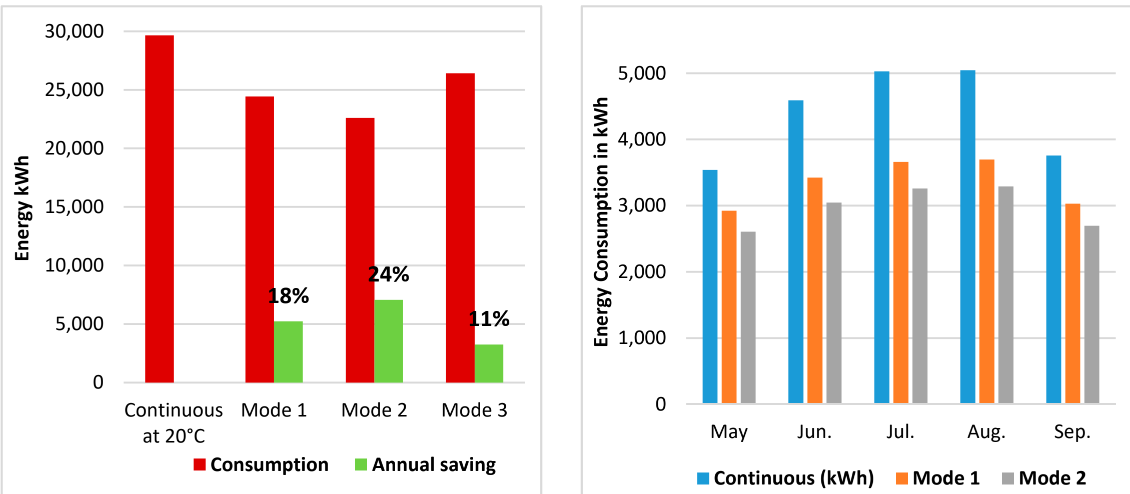


Figure 12. Actual readings and simulation results of energy consumption with thermostat setting to 20 °C under different AC operation modes for the villa.

Table 3 and Figure 13a show the results of the annual energy consumption simulation, including the energy savings over one year. Table 4 and Figure 13b indicated the results of the five summer months. The simulation results of the continuous air-conditioning system operation and Mode 1 and Mode 2 air-conditioning system operations for House 2, the villa, and the flat are given in Tables 5–10, respectively.

Table 3. Annual energy consumption under the continuous and different modes of AC operation for House 1.

AC system Operation Method	Annual Consumption (kWh)	Saving (kWh)	Annual Saving (%)
Continuous at 20 °C	29,661	0	0
Continuous at 21 °C	28,770	891	3%
Mode 1	24,430	5231	18%
Mode 2	22,598	7063	24%
Mode 3	26,417	3244	11%



(**a**) (**b**)

Figure 13. Simulation results of energy consumption at 20 °C thermostat setting under continuous mode, Mode 1 and Mode 2 operation of the air-conditioning systems for House 1: (**a**) Annual Consumption; (**b**) Consumption during the summer months.

Table 4. Monthly energy consumption under the continuous and different modes of AC operation for House 1 during the summer.

Months	Continue (kWh)	Mode1 (kWh)	Mode2 (kWh)	Mode 3 (kWh)	Mode 1 Saving (%)	Mode 2 Saving (%)	Mode 3 Saving (%)
May	3538	2922	2605	3913	17%	26%	16%
Jun.	4590	3423	3046	3695	25%	34%	19%
Jul.	5028	3661	3259	4023	27%	35%	20%
Aug.	5046	3696	3292	4047	27%	35%	19.%
Sep.	3757	3028	2695	2998	19%	28%	20%

Table 5. Annual energy consumption under the continuous and different modes of AC operation for House 2.

AC system Operation Method	Consumption (kWh)	Saving (kWh)	Annual Saving (%)
Continuous at 20 °C	39,355	0	0
Continuous at 21 °C	38,291	1,064	3%
Mode 1	27,314	1,2040	31%
Mode 2	24,885	1,4469	37%
Mode 3	34,989	4,366	11%

Table 6. Monthly energy consumption under the continuous and different modes of AC operation for House 2 during the summer.

Month	Simulation (kWh)	Mode 1 (kWh)	Mode 2 (kWh)	Mode 3 (kWh)	Mode 1 Saving (%)	Mode 2 Saving (%)	Mode 3 Saving (%)
May	5,918	3,974	3,537	4,853	33%	40%	18%
Jun.	6,974	4,496	4,002	5,614	36%	43%	19%
Jul.	7,320	4,849	4,316	5,856	34%	41%	20.%
Aug.	7,568	4,675	4,161	6,069	38%	45%	19%
Sep	5,036	6,343	4,087	4,089	36%	42%	18%

Table 7. Annual energy consumption under the continuous and different modes of AC operation for the Villa.

AC Operation Method	Consumption (kWh)	Saving (kWh)	Annual Saving (%)
Continuous	67,277	0	0
Mode 1	57,368	9,908	15%
Mode 2	52,786	14,490	22%
Mode 3	61,219	6,058	9%

Table 8. Monthly energy consumption under the continuous and different modes of AC operation for Villa during the summer.

Month	Simulation (kWh)	Mode 1 (kWh)	Mode 2 (kWh)	Mode 3 (kWh)	Mode 1 Saving (%)	Mode 2 Saving (%)	Mode 3 Saving (%)
May	7,647	5,879	4,997	6,347	23%	35%	17%
Jun.	8,608	6,585	5,597	7,016	24%	35%	18%
Jul.	9,035	6,905	5,870	7,246	24%	35%	20%
Aug.	9,315	7,124	6,056	7,452	24%	35%	20%
Sep.	7,879	6,083	5,474	6,240	23%	31%	21%

Table 9. Annual energy consumption under the continuous and different modes of AC operation for the Flat.

AC Operation Method	Consumption (kWh)	Saving (kWh)	Annual Saving (%)
Continuous	25,180	0	0
Mode 1	19,028	6,152	24%
Mode 2	18,168	7,012	28%
Mode 3	21,759	3,421	14%

Table 10. Monthly energy consumption under the continuous and different modes of AC operation for Flat during the summer.

Month	Simulation (kWh)	Mode 1 (kWh)	Mode 2 (kWh)	Mode 3 (kWh)	Mode 1 Saving (%)	Mode 2 Saving (%)	Mode 3 Saving (%)
May	3,530	2,362	2,128	2,852	33%	40%	19%
Jun.	3,713	2,492	2,280	2,896	33%	39%	22%
Jul.	3,909	2,620	2,490	3,010	33%	36%	23%
Aug.	3,942	2,640	2,479	3,000	33%	37%	23%
Sep.	3,544	2,372	2,249	2,694	33%	37%	20%

7. Discussion

We analyzed the simulation results for the annual electricity consumption and saving for each studied building. The results of the preceding section can be summarized as follows:

- For House 1, House 2, the villa, and the flat, the yearly savings achieved through Mode 1 operation mode were 18%, 31%, 15%, and 25%, respectively.
- For House 1, House 2, the villa, and the flat, the yearly savings achieved through Mode 2 operation mode were 24%, 37%, 22%, and 29%, respectively.
- For House 1, House 2, the villa, and the flat, the yearly savings achieved through Mode 3 operation mode were 11%, 11%, 9%, and 13%, respectively.

Herein, only the annual savings have been given. For the five summer months, the savings ranges from 16% to 35% for House 1, 18% to 45% for House 2, 17% to 35% for the villa, and 19% to 40% for the flat, depending on the ACs mode of operation.

Table 11 shows the corresponding savings for each house type category and the total savings for the city during the peak hour of 2:00 pm–3:00 pm. Accordingly, the total power needed for the whole of Riyadh during the peak-time hour is 8792 MW, which represents 43% of Riyadh during peak power demand; our data compares well with the residential portion (50% of total demand (20,329 MW)) as indicated in [4]. By applying the different AC operation modes that we proposed, the values of total power savings for the whole of Riyadh were 5026, 5608, and 1280 MW for Modes 1, 2, and 3, respectively, during peak hours. The results are summarized in Table 12.

Table 11. The total peak power and savings for each house on different AC operations modes for the whole of Riyadh region.

Dwelling's Name	AC Mode	Peak in (kW)	Number of Dwelling	Total Consumption (kW)	Total Saving (kW)
House 1	Continuous	6.3	127,466	803,036	0
	Mode 1	3.4	127,466	433,384	369,651
	Mode 2	2.85	127,466	363,278	439,758
	Mode 3	5.22	127,466	665,373	1,376,638
House 2	Continuous	7.5	47,596	356,970	0
	Mode 1	5.9	47,596	280,816	76,154
	Mode 2	3.6	47,596	171,346	185,624
	Mode 3	5.8	47,596	276,057	80,913
Villa	Continuous	17	374,900	6373,300	0
	Mode 1	6.2	374,900	2324,380	4,048,920
	Mode 2	5.65	374,900	2118,185	425,511
	Mode 3	14.61	374,900	5477,289	896,011
Flat	Continuous	4.5	279,708	1,258,686	0
	Mode 1	2.6	279,708	727,241	531,445
	Mode 2	1.9	279,708	531,445	727,241
	Mode 3	3.91	279,708	1,093,658	165,028

Table 12. The total peak power and saving of all houses types for the whole of Riyadh.

AC Operation Mode	Total (MW)	Saving (MW)	Annual Saving (%)
Continuous Mode	8792	0	0
Mode 1	3766	5026	25%
Mode 2	3184	5608	28%
Mode 3	7512	1280	7%

From the results, it can be observed that the savings achieved with Mode 3 (the remote-control mode) gave the lowest energy savings. The savings achieved with Mode 2 (the advanced control mode) gave the best energy savings. For the individual houses, the results of Mode 2 operation mode was superior to what was reported in the literature, that alleged it was possible to achieve up to 37% energy savings using a fixed monthly optimum thermostat setting [6]. In this study, it was not the optimum thermostat settings for each month that was used. Rather, it was the scheduling of the thermostat setting (in the case of Mode 1 and Mode 2) and the use of DR (in the case of Mode 3) throughout the summer months that led to better savings. In addition, another reason why the fixed monthly optimum thermostat setting described in [6] is impractical is that it presumes that home occupants will be willing to re-set their thermostat monthly to a new value. As was previously observed in the survey results, up to 66% of the respondents rarely or never shut down their ACs during the summer months, compared to 22% that usually do, while the remaining 12% fall between these two extremes. Moreover, it is unrealistic to expect that enough number of residents will manually turn off their air-conditioning systems [49]. This is confirmed by SEEC, which often send reminders and requests that people in KSA set their thermostat to 24 °C; their call is mostly always ignored [5], as the low energy tariff and the operative temperature may not provide comfort for occupants due to the high ambient temperature and lack of thermal insulation in about 70% of the residential buildings [8]. Thus, Mode 1 and Mode 2 solutions allows the air-conditioning systems to run on a scheduled non-continuous basis. Mode 3 uses the DR approach, where the utilities can automatically control the thermostat settings of the air-conditioning systems of households, if and when appropriate. Consequently, the proposed approaches do not require daily thought or actions from occupants to achieve energy savings. Furthermore, these modes are realistic and practical as they do not require home occupiers' intervention to change the thermostat settings.

8. Limitation

The survey method undertaken in this study has indicated the range of domestic energy use patterns. It cannot necessarily capture the full range of behaviors, in the absence of any more exhaustive survey data.

The hourly electricity consumption data for individual dwellings in KSA was not available; measurements of hourly energy consumption need to be undertaken as a future work.

Sensors are central to achieving the smart control of AC. However, to achieve the level of savings obtained in this study, the residential buildings will require sensors capable of detecting occupancy with a high degree of accuracy to obtain the schedule that can be periodically updated. Occupancy sensor technologies are an area of on-going research and future work should focus on the development of cheap, high accuracy occupancy sensors without the challenges of privacy and data intrusiveness. Still, regarding AC Modes 1 and 2, the control system and associated sensors must be a standalone system, without interference from the utility company in order to respect privacy.

The monthly bills for houses could be obtained through using applications available on customer mobiles. This could also provide an overview of the previous three years of consumption. However, it is difficult to get details regarding houses, such as geometry information, occupants' behavior pertaining to times of rooms occupied, and usage of households' appliances, as most occupants deem this information confidential.

9. Recommendations

A program to support evidence based policymaking should be a comprehensive nationwide survey designed to obtain statistically valid data on energy use patterns. In order to achieve the much-needed savings in energy consumption via AC systems in the residential sector, the electricity policy makers and stakeholders could encourage both utility companies and residents to use AC smart controls in the context of DSM. Additionally, utility companies could be given a period of time to ensure that a percentage of their customers deploy AC systems equipped with smart scheduling and controls in their house in order to increase their percentage gradually. Moreover, the companies that provide these technologies could be supported through facilities, such as tax reduction or tax relief.

To reduce the AC consumption during the peak time, utility companies might encourage their customers to reduce their energy by subscribing to a DR scheme to let the companies control some or most of their AC units during the peak hours. The utility company could provide financial incentives for the customers in the form of free hours in off-peak time or reduce the monthly bills by a particular percent. To be ethical, these actions can only be based on the mutual agreement between the utility companies and their customers [37,50,51].

10. Conclusions

In this paper, we presented potential solutions to the high energy demand associated with the use of air-conditioning systems in KSA residential areas. The main idea of the proposed solutions is that it is possible to reduce air-conditioning energy consumption through appropriate scheduling or remote thermostat setting, while the comfort level of the building is set to an acceptable level. Using the DesignBuilder® software, the results of the three modes of operation show that they can effectively reduce energy consumption and, in the advance mode of operation (Mode 2), can achieve up to 30% to 40% total annual energy savings, or 30% to 45% during the summer months, depending on the house type. However, to achieve this level of saving, the computer simulation assumes that residential buildings are equipped with sensors capable of detecting occupancy with a high degree of accuracy in order to obtain the schedule that can be periodically updated.

Future work should look into other types of domestic appliances, in addition to AC systems, that will be good DR candidates, in order to achieve an even larger amount of energy savings. Furthermore, it would be worthwhile to investigate the energy savings achievable with other techniques the can control AC systems based on occupancy behavior obtained from high accuracy occupancy sensors. Artificial intelligence techniques that combine sensor information with other data, such as mobile phone use, are an area of on-going research that could provide helpful assistance in this area. Moreover, future work should investigate the extension of the modes of AC operations proposed for the residential sector to government buildings, such as mosques and schools, and to other sectors. Mosques and schools are particularly suitable because they are opened only during specific times of the day, making them good candidates for AC system operation scheduling.

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Appendix A

Public Survey and Questionnaire

Welcome to My Survey

I am Jubran, a PhD student at Faculty of Technology, De Montfort University. As part of my research I am collecting data to assess the wastage of energy in Saudi homes. The main objectives are as follows:
1. to propose smart solutions to reduce the waste of electrical energy in homes;
2. to manage electrical demand from the consumer side;
3. to involve the citizen (consumer) solutions in energy conservation;

By answering a questionnaire you are agreeing to participate voluntarily.
Your name or any other personal identifying information will not appear in any publications resulting from this study.
The information gained from this questionnaire will only be used for the above objectives, will not be used for any other purpose and will not be recorded in excess of what is required for the research.
You may decide to withdraw from this study at any time by advising the researcher on email: p1401984x@myemail.dmu.ac.uk

1. What is your gender?
- Female
- Male

2. In what Region do you live?
- Central Region
- West Region
- East Region
- North Region
- South Region

* 3. What is the type of your accommodation?
- Villa
- Traditional house (one floor)
- Apartment
- Other (please specify)

4. How much amount of money in Saudi Riyals do you pay for electricity bill monthly?

100 - 300	301 - 500	501 - 700	701 - 900	More than 900
◯	◯	◯	◯	◯

Other (please specify)

5. How many family members normally live in the accommodation?

- ◯ more than 7
- ◯ 7
- ◯ 6
- ◯ 5
- ◯ 4
- ◯ 3
- ◯ 2

* 6. How many guest rooms are there in your house?
(Guest rooms = Men's living room + women's living room + dining room)

- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4 or more

Other (please specify)

7. How many bedrooms are there in your house?

- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ more than 7

* 8. How many bathrooms are there in your house?

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- more than 7

* 9. How many heating water cylinders are there in your house?

- less than 3
- 3
- 4
- 5
- 6
- 7
- More than 7

* 10. How many air conditioning units are there in your house?

- 3 or less
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- more than 10

* 11. What kind of air conditioning units are there in your house?

- ◯ Window
- ◯ Split
- ◯ Combined of window and split
- ◯ Central

Other (please specify)

12. Which appliances have the highest electricity costs (consumption)?
(you can choose more than one answer)

- ☐ Air conditioning
- ☐ Wash machine
- ☐ Dish washer
- ☐ Water heater

13. How many days a week is the men's guest room occupied?

1 days	2 days	3 days	4 days	5 days or more
◯	◯	◯	◯	◯

Other (please specify)

14. On typical days, which intervals by hours is the men's guest room used?
(you can choose more than one answer)

- ☐ 8 am - 11 am
- ☐ 11 am - 3 pm
- ☐ 3 pm - 7 pm
- ☐ 7 pm - 11 pm
- ☐ After 11 pm
- ☐ Most of the time

Other (please specify)

15. How many days a week is the women's guest room occupied?

1 days	2 days	3 days	4 days	5 days or more	No women's guest room
○	○	○	○	○	○

Other (please specify)

16. On typical days, which intervals by hours is the women's guest room used? (you can choose more than one answer)

- ☐ 8 am - 11 am
- ☐ 11 am - 3 pm
- ☐ 3 pm - 7 pm
- ☐ 7 pm - 11 pm
- ☐ After 11 pm
- ☐ Most of the time

Other (please specify)

17. How many days a week is the dining room occupied?

1 days	2 days	3 days	4 days	5 days or more	No dining room
○	○	○	○	○	○

Other (please specify)

* 18. On typical days, which intervals by hours is the dining room occupied?
You can choose more than one answer

- [ ] 5 am - 8 am
- [ ] 8 am - 11 am
- [ ] 11 am - 3 pm
- [ ] 3 pm - 11 pm
- [ ] After 11 pm
- [ ] Most of the time
- [ ] No lounge

Other (please specify)

* 19. On typical days, which intervals by hours are bedrooms occupied?
You can choose more than one answer

- [ ] 5 am - 8 am
- [ ] 8 am - 11am
- [ ] 11 am - 3 pm
- [ ] 3 pm - 7 pm
- [ ] 7 pm - 11 pm
- [ ] After 7 pm (sleeping time)

Other (please specify)

* 20. How many bedroom are rarely occupied?
(or used as a store)

- [ ] 1
- [ ] 2
- [ ] 3
- [ ] more than 3

Other (please specify)

* 21. On typical days, which intervals by hours is the lounge occupied?
You can choose more than one answer

- ☐ 5 am - 8 am
- ☐ 8 am - 11 am
- ☐ 11 am - 3 pm
- ☐ 3 pm - 11 pm
- ☐ After 11 pm
- ☐ Most of the time
- ☐ No lounge

Other (please specify)

* 22. At which temperature do you often adjust the air conditioning thermostat in summer?

- ○ Below 18°C
- ○ Between 18 - 20°C
- ○ Between 21 - 23°C
- ○ Between 23 - 25°C
- ○ more than 25 °C

Other (please specify)

* 23. How often do you remember to shut-down the Air-Conditioning (A/C) when you are leaving any room in your house?

always	usually	sometimes	rarely	never
○	○	○	○	○

24. How many heating water cylinders do you switch on in the summer?

- all
- 1
- 2
- 3
- 4 or more
- None
- Other (please specify)

* 25. To what extent do you agree to adopt technical solutions in your home to reduce wasted energy?

Strongly Disgree	Disagree	Neutral	Agree	Strongly Agree
○	○	○	○	○

Other (please specify)

* 26. To what extent do you agree to install an automatic A/C (air conditioning)- control system if it will reduce your bill?

Strongly Disgree	Disagree	Neutral	Agree	Strongly Agree
○	○	○	○	○

* 27. Do you know what the term "renewable energy" means?

- I do not know
- I hear about it but I do not know what does it mean
- I know a little bit
- Yes I know

* 28. To what extent do you agree with installation of solar cells on your house roof?

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
○	○	○	○	○

Other (please specify)

References

1. STO-Website. Climate in Saudi Arabia; Saudi Arabia Travel Guide. 2018. Available online: http://www.saudiarabia-travel.org/weather.html (accessed on 17 December 2017).
2. Electricity and Cogeneration Regulatory Authority (ECRA). In *Annual Statistical Booklet for Electricity and Seawater Desalination Industries*; Electricity and Cogeneration Regulatory Authority (ECRA): Riyadh, Saudi Arabia, 2014.

3. Alrashed, F.; Asif, M. Saudi building industry's views on sustainability in buildings: Questionnaire survey. *Energy Procedia* **2014**, *62*, 382–390. [CrossRef]
4. Electricity and Cogeneration Regulatory Authority (ECRA). In *Annual Statistical Booklet for Electricity and Seawater Desalination Industries*; Electricity and Cogeneration Regulatory Authority (ECRA): Riyadh, Saudi Arabia, 2015.
5. SEEC. SEEC-Website; Saudi Energy Efficiency Centre. 2017. Available online: http://www.seec.gov.sa/en (accessed on 26 July 2018).
6. Al-Sanea, S.A.; Zedan, M.F. Optimized monthly-fixed thermostat-setting scheme for maximum energy-savings and thermal comfort in air-conditioned spaces. *Appl. Energy* **2008**, *85*, 326–346. [CrossRef]
7. Taleb, H.M.; Sharples, S. Developing sustainable residential buildings in Saudi Arabia: A case study. *Appl. Energy* **2011**, *88*, 383–391. [CrossRef]
8. Mujeebu, M.A.; Alshamrani, O.S. Prospects of energy conservation and management in buildings—The Saudi Arabian scenario versus global trends. *Renew. Sustain. Energy Rev.* **2016**, *58*, 1647–1663. [CrossRef]
9. Aldossary, N.A.; Rezgui, Y.; Kwan, A. An investigation into factors influencing domestic energy consumption in an energy subsidized developing economy. *Habitat Int.* **2015**, *47*, 41–51. [CrossRef]
10. Vine, E.L. Saving energy the easy way: An analysis of thermostat management. *Energy* **1986**, *11*, 811–820. [CrossRef]
11. Maheshwari, G.P.; Al-Taqi, H.; Suri, R.K. Programmable thermostat for energy saving. *Energy Build.* **2001**, *33*, 667–672. [CrossRef]
12. Lu, J.; Sookoor, T.; Srinivasan, V.; Gao, G.; Holben, B.; Stankovic, J.; Field, E.; Whitehouse, K. The smart thermostat: Using occupancy sensors to save energy in homes. In Proceedings of the 8th ACM Conference on Embedded Networked Sensor Systems, Zürich, Switzerland, 3–5 November 2010; pp. 211–224.
13. Al-Ajlan, S.A.; Al-Ibrahim, A.M.; Abdulkhaleq, M.; Alghamdi, F. Developing sustainable energy policies for electrical energy conservation in Saudi Arabia. *Energy Policy* **2006**, *34*, 1556–1565. [CrossRef]
14. Al-Shaalan, A.M. EER improvement for room air-conditioners in Saudi Arabia. *Energy Power Eng.* **2012**, *4*, 439. [CrossRef]
15. Budaiwi, I.; Abdou, A.; Al-Homoud, M. Variations of thermal conductivity of insulation materials under different operating temperatures: Impact on envelope-induced cooling load. *J. Archit. Eng.* **2002**, *8*, 125–132. [CrossRef]
16. Budaiwi, I.M. An approach to investigate and remedy thermal-comfort problems in buildings. *Build. Environ.* **2007**, *42*, 2124–2131. [CrossRef]
17. Aldossary, N.A.; Rezgui, Y.; Kwan, A. Energy consumption patterns for domestic buildings in hot climates using Saudi Arabia as case study field: Multiple case study analysis. *Comput. Civil Build. Eng.* **2014**, *2014*, 1986–1993.
18. Omer, A.M. Energy, environment and sustainable development. *Renew. Sustain. Energy Rev.* **2008**, *12*, 2265–2300. [CrossRef]
19. Taleb, H.M.; Pitts, A.C. The potential to exploit use of building-integrated photovoltaics in countries of the Gulf Cooperation Council. *Renew. Energy* **2009**, *34*, 1092–1099. [CrossRef]
20. Mahdavi, A.; Pröglhöf, C. *User Behavior and Energy Performance in Buildings*; Energiewirtschaftstagung an der TU Wien: Wien, Austria, 2009; pp. 1–13.
21. Robinson, D. Some trends and research needs in energy and comfort prediction. In *Comfort and Energy Use in Building*; Windsor, UK, 2006.
22. Kwok, S.S.K.; Lee, E.W.M. A study of the importance of occupancy to building cooling load in prediction by intelligent approach. *Energy Convers. Manag.* **2011**, *52*, 2555–2564. [CrossRef]
23. Oldewurtel, F.; Sturzenegger, D.; Morari, M. Importance of occupancy information for building climate control. *Appl. Energy* **2013**, *101*, 521–532. [CrossRef]
24. Bloomfield, D.P.; Fisk, D.J. The optimisation of intermittent heating. *Build. Environ.* **1977**, *12*, 43–55. [CrossRef]
25. McLorn, G.; Sheikh, A.; Rob, R. Evaluation of peak-shifting techniques for residential air conditioning demand in Saudi Arabia. In Proceedings of the IEEE PES Innovative Smart Grid Technologies, Europe, Istanbul, Turkey, 12–15 October 2014; pp. 1–5.
26. Hasnain, S.M.; Alabbadi, N.M. Need for thermal-storage air-conditioning in Saudi Arabia. *Appl. Energy* **2000**, *65*, 153–164. [CrossRef]

27. Maqbool, S.D.; Ahamed, T.P.I.; Al-Ammar, E.; Malik, N.H. Demand response in saudi arabia. In Proceedings of the 2011 2nd International Conference on Electric Power and Energy Conversion Systems (EPECS), Sharjah, UAE, 15–17 November 2011; pp. 1–6.
28. Taqqali, W.M.; Abdulaziz, N. Smart grid and demand response technology. In Proceedings of the 2010 IEEE International Energy Conference and Exhibition (EnergyCon), Manama, Bahrain, 18–22 December 2010; pp. 710–715.
29. Faruqui, A.; Sergici, S. Household response to dynamic pricing of electricity: A survey of 15 experiments. *J. Regul. Econ.* **2010**, *38*, 193–225. [CrossRef]
30. Aljahdali, F.; Abbod, M. Design of Smart Energy Generation and Demand Response System in Saudi Arabia. In Proceedings of the 2017 52nd International Universities Power Engineering Conference (UPEC), Heraklion, Greece, 28–31 August 2017.
31. Matar, W. A look at the response of households to time-of-use electricity pricing in Saudi Arabia and its impact on the wider economy. *Energy Strateg. Rev.* **2017**, *16*, 13–23. [CrossRef]
32. Haider, H.T.; See, O.H.; Elmenreich, W. A review of residential demand response of smart grid. *Renew. Sustain. Energy Rev.* **2016**, *59*, 166–178. [CrossRef]
33. Adika, C.O.; Wang, L. Smart charging and appliance scheduling approaches to demand side management. *Int. J. Electr. Power Energy Syst.* **2014**, *57*, 232–240. [CrossRef]
34. Darby, S.J.; McKenna, E. Social implications of residential demand response in cool temperate climates. *Energy Policy* **2012**, *49*, 759–769. [CrossRef]
35. Gyamfi, S.; Krumdieck, S.; Urmee, T. Residential peak electricity demand response—Highlights of some behavioural issues. *Renew. Sustain. Energy Rev.* **2013**, *25*, 71–77. [CrossRef]
36. Hamidi, V.; Li, F.; Robinson, F. Demand response in the UK's domestic sector. *Electr. Power Syst. Res.* **2009**, *79*, 1722–1726. [CrossRef]
37. Mohagheghi, S.; Stoupis, J.; Wang, Z.; Li, Z.; Kazemzadeh, H. Demand response architecture: Integration into the distribution management system. In Proceedings of the 2010 First IEEE International Conference on Smart Grid Communications (SmartGridComm), Gaithersburg, MD, USA, 4–6 October 2010; pp. 501–506.
38. Goldsworthy, M. Towards a Residential Air-Conditioner Usage Model for Australia. *Energies* **2017**, *10*, 1256. [CrossRef]
39. Li, Z.; Jiang, Y. Characteristics of cooling load and energy consumption of air conditioning in residential buildings in Beijing. *Heat. Vent. Air Cond.* **2006**, *36*, 1–6.
40. Weible, J.W.R. Cyber research: The impact of the Internet on data collection. *Mark. Res.* **1988**, *10*, 1.
41. Huang, H.M. Do print and Web surveys provide the same results? *Comput. Hum. Behav.* **2006**, *22*, 334–350. [CrossRef]
42. Goodman, L.A. Snowball Sampling. *Ann. Math. Stat.* **1961**, *32*, 148–170. [CrossRef]
43. Kaneesamamkandi, Z.; Almujahid, A.; Al-Sanea, S.A. Recent Developments in Efficiency Enhancement of Non-Concentrating Photovoltaic Systems By Thermal Methods. *Appl. Mech. Mater.* **2015**, *786*, 226–231. [CrossRef]
44. Lasker, W.J.A. The Future of the Renewable energy of Saudi Arabia (Jeddah). MSc. dissertation, Heriot-Watt University, Edinburgh, UK, 2011.
45. General Authority for Statistic. *Housing Survey 2017*; General Authority for Statistic: Riyadh, Saudi Arabia, 2017. Available online: https://www.stats.gov.sa/en/911-0 (accessed on 23 June 2017).
46. Macdonald, I.A.; Clarke, J.A.; Strachan, P.A. Assessing uncertainty in building simulation. *Proc. Build. Simul.* **1999**, *99*, 1–8.
47. Coakley, D.; Raftery, P.; Molloy, P. Calibration of whole building energy simulation models: Detailed case study of a naturally ventilated building using hourly measured data. In Proceedings of the First Building Simulation and Optimization Conference, Loughborough, UK, 10–11 September 2012; pp. 57–64.
48. SEEC. SEEC-Website. 2017. Available online: http://www.seec.gov.sa/en/content/establishment (accessed on 2 August 2017).
49. Sachs, H. *Programmable Thermostats*; American Council for an Energy-Efficient Economy (ACEEE): Washington, DC, USA, 2004.

50. Siano, P. Demand response and smart grids—A survey. *Renew. Sustain. Energy Rev.* **2014**, *30*, 461–478. [CrossRef]
51. Yoon, J.H.; Bladick, R.; Novoselac, A. Demand response for residential buildings based on dynamic price of electricity. *Energy Build.* **2014**, *80*, 531–541. [CrossRef]