Non-intrusive Electricity Sub-metering in Selected Households in Qatar

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***Abstract*—Per-capita electricity consumption in the Gulf region is one of the highest in the world due to high disposable incomes, year-long need to air conditioning, and energy subsidies. Electrical consumption data and load profiles of major household appliances are crucial elements for demand response programs which aim to reduce electricity consumption. In this study, we choose three typical villa-type accommodation in the State of Qatar and deployed multiple smart energy monitors to gain insights about energy consumption patterns. Measurement study covered the first five months of 2019 and the data is recorded at every five minutes. Electricity bills of all houses are subsidized by their employees, hence, results provide an opportunity to reveal the impacts of subsidies on consumption patterns. The analyses show that air conditioning (AC) and water heater loads are the major electricity consumers and significant demand savings can be achieved by introducing applications for them. To the best of author's knowledge, this is the first study conducted in the Gulf region that presents the measurement of appliance-level electricity consumption.**

***Index Terms*—Load monitoring, submetering, energy subsidies**

I. Introduction

Qatar has one the highest per capita electricity consumption in the world, yet, little is currently known about domestic electricity consumption. The residential sector accounts for nearly 59% of the overall consumption [1]. Over the past five years, Qatar has witnessed a significant population growth of 35%, which lead to a surge of 47% growth in peak electricity consumption and 46% growth in total electricity generation. As energy subsidies lead to budget deficits and overconsumption of carbon resources, there is a pressing need to examine the residential load profile to understand consumption patterns better and uncover potential solutions for more efficient usage. To achieve this, in this paper, we deployed multiple smart energy monitors at three selected villa type accommodations in Qatar. Energy monitors are dedicated to major loads such as air conditioning (AC), water heater, and kitchen.

Residential load profiles are typically influenced by seasonal and socio-economic factors [2]. Especially, arid climates necessitate significant amounts of energy for air and water cooling [3]. Identifying such factors further enables decision-makers to devise effective demand-side policies to reduce and manage electricity consumption. Furthermore, there is a global motivation towards the adoption of renewable energy source, and Qatar has initiated plans to deploy PV systems of 700 MW by 2021 and 900 MW generation capacity in the upcoming years [4].

Load profiling studies are closely related to demand side management which can be described as the set of activities that manage the timing and amount of energy consumed by the customer in a cost-effective manner. DSM uses different measures to control the electric loads such as pricing-based, incentive-based, and remote load control. Residential load profiles enable system operators to devise effective policies reduce consumption levels based on flexibility of electrical loads.

The electricity load profile of a residential unit can be measured through an intrusive or a non-intrusive load monitoring technique [5]. In intrusive load monitoring, each appliance is monitored separately via measurement devices. This method has high accuracy and enables individual load monitoring. This method has two major issues. First, it is very costly and requires dedicated monitoring equipment for each load. Second, it creates greater discomfort as it takes longer to install and dismantle, and occupies more physical space. The second method, non-intrusive power monitoring (NIPM) which overcomes the discomfort issue at the cost of lower load precision. NIPM requires a single meter at the point of the household supply. In NIPM, each appliance recognition is typically conducted by analyzing the electrical signatures of electrical loads via machine learning algorithms [6]. In a load monitoring study [7], the electricity consumption of 12 houses in Canada was measured with 1-minute resolution. Another measurement study is presented in [8] in which authors monitored the electricity consumption of 60 low-energy buildings in South Australia. A number of public datasets related to appliance load profiles are also available [9].

In our previous work [1], we analyzed the electricity load profiles in Qatar and showed that peak consumption occurs during summer afternoons while winter demand is almost as half as the summer demand. In addition, we showed that subsidized tariffs lead to over-consumption and weekend and weekdays profiles are very similar. Moreover, in [10] we quantified the cost of cooling in Qatar and showed that more than half the summer load represents cooling demand.

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TABLE I: Characteristics of the measured houses (H:House)

	H1	H2	H3
Size (sqm)	220	315	389
Building Age (years)	11-15	11-15	11-15
# of Occupants	2	3	4
Annual Household Income (USD)	101-200k	101-200k	0-100k
Electricity Subsidized	Yes	Yes	Yes
Cooling Type	Central	Central	Central

II. Data Collection

Monitored houses are located at Qatar Foundation's Education City Community Housing Complex which is dedicated for faculty and staff [11]. As shown in Table I, some important properties of the test sites are presented as physical size, air-conditioner type, and the fact that all three houses do not pay electricity bills. Moreover, all three houses have high disposable income when compared to country average [12]. Hence, consumption patterns are expected to be high when compared to rest of the country [13].

To collect electricity profiles, we deployed multiple Smappee energy monitors at each house [14]. The standards of the residential electric network in Qatar is similar to the one in the United Kingdom, and it is rated at 240V and 50Hz. Furthermore, due to the large loads located in residential premises (e.g., air-conditioner, water heater, etc.), electric power is typically supplied in three phases. The monitoring device measures power flow in a non-intrusive way by using current clamps attached to the main circuits located at the distribution boards. It is noteworthy that each house has three distribution boards dedicated to (1) ground floor appliances such as kitchen, wet appliances, TV, etc.; (2) Water heater, hairdryer, electronics, etc.; and (3) Central air-conditioner. In our measurements, we deployed one monitoring device to each distribution and measure the consumption. The monitor requires Wi-Fi connectivity to upload and save power readings (in Watts) at every five minutes to the cloud server provided by the manufacturer. An overview of the measurement devices for House 2 is presented in Fig. 1.

The accuracy of the measurements relates to clamp capacity and power factor of the electrical load. Employed clamp meters had 50-ampere rating which is selected based on the size of the distribution board cables. According to the local utility company's regulations and its power correction facilities maintain the residential power factor above 90%; therefore, it can be concluded that the accuracy of the energy monitor is around 90% of the actual consumption.

III. Results & Discussion

In this section, we present the results of electricity submetering collected during the first five months of 2019. Even though five-minute resolution data is available, due to page limitations, we present daily energy consumption for each monitor. In Fig.2(a), we show daily consumption of ground floor appliances. It can be observed that consumption is related to occupant number and appliance types. In H1, residents use

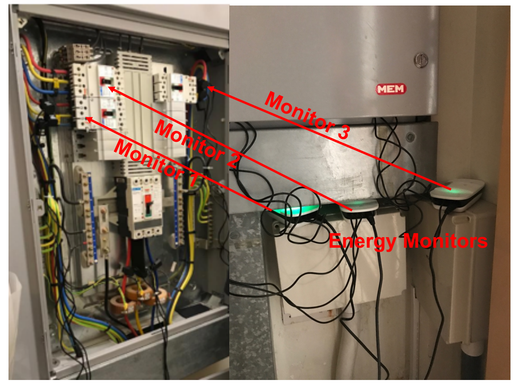


Fig. 1: Overview of electricity submetering system.

energy-efficient washing machine (LG direct drive A+) and do not use clothes dryer while H2 and H3 use 15+-year-old washer and dryer (220VAC 30Amps). Moreover, residents of H1 are professionals who are at work during the day, while there is at least one resident present during the day for H2 and H3.

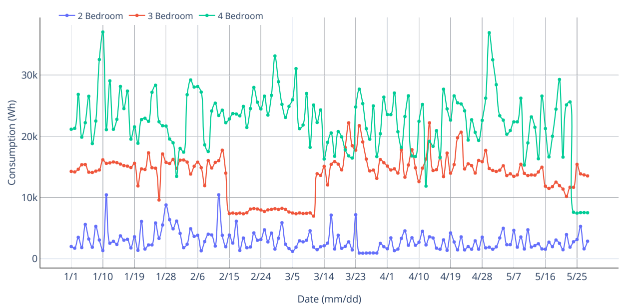
Daily consumption records of monitor 2 is presented in Fig.2(b). In the first floor, major electricity consumer of all houses is the water heater which stores about 50 gallons of water and draws 4.5 kW of power. Two important parameters determine the use of a water heater tank: (1) temperature set point and (2) occupants' water usage patterns. To that end, houses with high occupant numbers consume more electricity. This can be further observed by investigating the last week of May when residents of H2 and H3 were on vacation. Consumption levels drops and electricity is used mostly for keeping the water at temperature set point.

Next, we present the results for air-conditioning (AC) loads. AC loads depend highly on seasonal factors and customer comfort levels [1]. Recall that all three houses employ central AC units which further includes a ventilation system. Therefore, unless the entire system is shut down manually, ventilation fans (1-2 kW rate power) to work continuously. As shown in Fig.3(c), AC consumption gradually increases as the outdoor temperature increase from January to May. It is noteworthy that three bedroom villa (H3) consumes more electricity than the four-bedroom one because H3 has a lower set point than H4 (22-degree Celsius versus 25-degree Celsius). Finally, in Table II, we present the percentage of electricity consumption for each monitor. It can be seen that majority of the consumption is used for air conditioning and water heating activities.

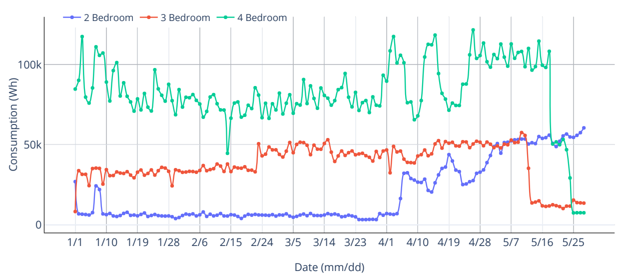
To provide further insights, we present consumption patterns of major appliances. In all ground floors, there are identical appliances in kitchen such as fridge and cooker (depicted in Fig.3(a)). The fridge is an inductive load and nearly follows an On-Off process, which is determined by the set temperature. Cooker, on the other hand, is resistive load and its magnitude depends on the number and the cooker level. In Fig.3(b), we present consumption pattern of a water heater for a day when

TABLE II: Percentage (%) of electricity consumption at House. Monitor 1: Kitchen, wet appliances, TV ground floor lights. Monitor 2: Water heater, electronics, hair dryer, first lights. Monitor 3: Central AC unit.

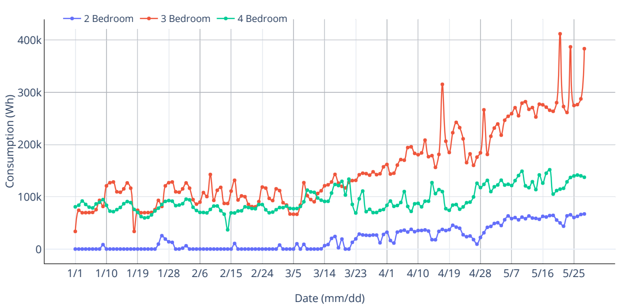
	House 1			House 2			House 3		
	Monitor 1	Monitor 2	Monitor 3	Monitor 1	Monitor 2	Monitor 3	Monitor 1	Monitor 2	Monitor 3
January	25.63	53.33	21.04	10.81	22.72	66.47	12.33	45.14	42.54
February	32.96	58.46	8.57	7.77	22.38	69.85	13.92	42.44	43.64
March	12.95	28.49	58.56	7.56	24.81	67.63	11.54	40.29	48.17
April	4.21	44.89	50.90	6.30	17.40	76.29	11.35	44.71	43.95
May	2.67	46.73	50.60	4.57	16.01	79.43	9.41	42.50	48.09



(a) Monitor 1: Kitchen, wet appliances, TV, etc.

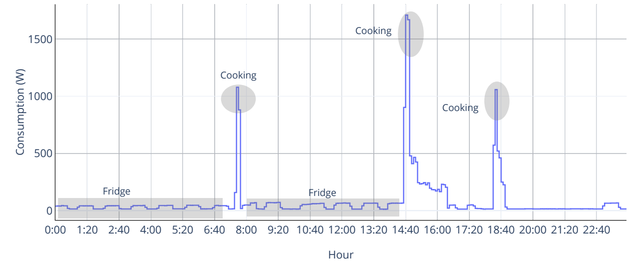


(b) Monitor 2: Water heater, hair dryer, electronics, etc.

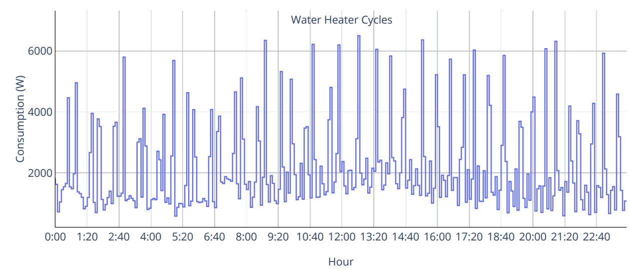


(c) Monitor 3: Central Air-conditioner.

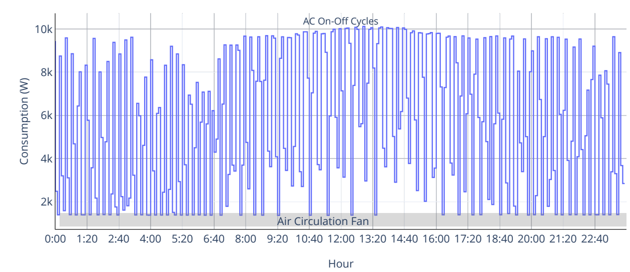
Fig. 2: Energy consumption comparison of measured houses.



(a) Ground floor appliance profile.



(b) First floor appliance profile.



(c) Air conditioning profile.

Fig. 3: Appliance profiles.

residents are on vacation. It can be seen that, the water heater is periodically turned on and off to keep the stored water within predefined limits. Finally, we present the load pattern of the AC unit in Fig. 2(c). Similar to the water heater, AC unit has on and off cycles, in addition to cool air circulation fan. It is noteworthy that, in most demand response applications, such as direct load control of air conditioners [15], circulation fan is kept open while the compressor is cycled off.

In the results presented in Figs. 2(a), 2(b), and 2(c), it can be observed that there are sudden drops in electricity consumption for certain periods (e.g., see Fig.2(a) H3 from late February to early March). This is because the expat population in Qatar is

TABLE III: Standby energy (kWh) consumption during June 1-7, 2019.

House	Monitor 1	Monitor 2	Monitor 3	Total	PV system (kW)
H1	0.7	60.3	75.8	136.8	127
H2	8.5	49.5	332.8	390.8	362
H3	7.6	46.3	138.2	192.0	178

quite high and residents take extended vacations [16]. As a last calculation, we present standby energy consumption of houses for different periods of the year. Then, we calculate the size of a photovoltaic (PV) system that would be needed to generate standby energy. All residents of the three houses were on vacation during a national holiday from June 1, 2019- to June 7, 2019. In Table III, we present the averaged daily standby energy for the holiday week. Next, using ground measurements (see [17]), we calculate the equivalent size of PV systems (1.5m^2, 15% efficiency) to generate standby energy. Note that the average global horizontal irradiance for the first week of June 2019 was 7.2 kWh/m^2. It can be seen that due to high consumption deploying enough PV systems on the rooftop is not practical.

IV. Conclusions

In this paper, we have presented a measurement based study to reveal appliance-level electricity consumption in Qatar. We deployed dedicated energy monitors to major appliances and analyzed the results for the first five months of 2019. The results showed that air conditioning and water heating are the two major consumers of electricity, hence, future demand response programs should focus on them. In the final part, we calculated how much energy is consumed when the residents were on vacation. It was concluded that even standby energy consumption is enormous and rooftop PV systems cannot generate enough electricity to meet household demand. As future work, we will focus on analyzing the rest of the year. Then, by using collected data, we will devise and experiment demand-response applications to reduce electricity consumption.

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