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Unlocking Household Electricity Consumption in Pakistan

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Abstract: In Pakistan, data for household electricity consumption are available in the form of monthly electricity bills only, and, therefore, are not helpful in establishing appliance-wise consumption. Further, it does not help in establishing the relationship among the household electricity consumption and various driving factors. This study aimed to unlock the household electricity consumption in Pakistan by analyzing electricity bills and investigating the impact of various socioeconomic, demographic, and dwelling parameters and usage of different appliances. The methodology adopted in this study was survey-based data collection of the residential sector. For this purpose, data were collected from 523 dwellings through surveys and interviews in Mirpur city. The results of the data analysis revealed that the average household electricity consumption is 2469 kWh/year with an average family size of seven and an average floor area of 78.91 m^2. Based on possession of various appliances, the households were categorized into four types and their consumption patterns were established and compared. Air Conditioned (AC) houses consume 44% more electricity compared to the non-AC houses, whereas an Uninterrupted Power Supply (UPS) consumes electricity equivalent to an AC. The research findings are useful for policy makers and building designers and are discussed in the conclusion section.

Keywords: electricity consumption; residential sector; electrical appliances; socioeconomic and demographic; building characteristics

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1. Introduction

Energy is often regarded as the backbone of a country's economic and human development [1]. Global energy demand has been increasing exponentially at a yearly average rate of 2.2% since 1965. The world energy outlook has already predicted it to increase by 30% between today and 2040 [2,3]. Globally, 30–40% percent of the total energy is consumed in the building sector, of which residential buildings consume three-fourths of the total buildings' consumption [4]. The varying climatic conditions with increasing population, economic development, and human growth have resulted in an increased demand for energy in the building sector. Therefore, energy-efficient and sustainable buildings are imperative to build an equilibrium between the present and future energy demands of a country.

Pakistan is among those countries that have the highest share of energy consumption (55%) in buildings compared to the developed countries such as the USA (39%), Canada (27%), and China (20%) [5]. In 2018, the residential buildings consumed 41.45 TWh (46%) of electricity, whereas the commercial buildings consumed 6.51 TWh (8%) of electricity during the same period [6]. Electricity is mainly supplied through the fossil fuels-based thermal power plants that have the highest share (62%) in the electricity generation of Pakistan, whereas hydroelectric power plants supply 26% of the total annual electricity [7] (Figure 1).

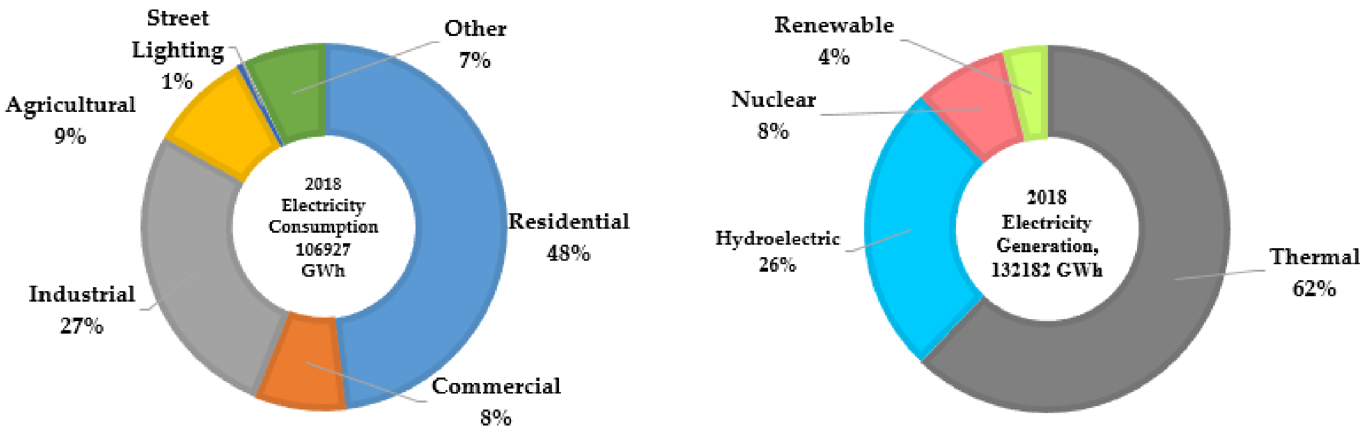


Figure 1. Electricity generation and consumption (share of different sources and sectors) [7].

Pakistan's electricity consumption in buildings today has increased by 26.46% since 2006 with an annual increase rate of +2.9% [8]. This increasing trend in residential buildings' energy consumption demands effective building codes and policies. Understanding residential buildings' energy consumption could help policy makers in the preparation of effective building codes. Residential buildings' energy consumption depends on various factors such as family size, floor area of the house, number and power ratings of electrical appliances, building fabric, etc. Identification of such factors could be helpful in devising future energy strategies. Similarly, understanding electricity consumption by different electrical appliances could help in developing the load profile of the building.

Although a number of research studies are available on residential buildings' energy consumption for different countries such as Indonesia, Malaysia, Thailand, and Vietnam [9], there is no such detailed study available about electricity consumption in the residential sector of Pakistan. Amber et al. [10] collected and analyzed data of 523 homes in Pakistan and identified some key factors driving the electricity consumption in the residential buildings. Their study found that a typical house in Pakistan consumes 24 kWh/m^2/year of electricity. While this study may be a useful guide, it does not unlock the entire picture of the electricity consumption of a typical residential building. Therefore, to understand various aspects of electricity consumption in Pakistani residential buildings, a detailed study is indispensable and should focus on a comprehensive set of data collection. However, data collection in a country such as Pakistan is not an easy task, especially when the data are only available in the form of monthly electricity bills.

The present study attempted to fill this knowledge gap by collecting data from dwellings through surveys and interviews with the house owners. The following objectives were set: (1) to understand and develop annual and monthly electricity consumption profiles of Air Conditioned (AC) and non-AC homes by analyzing the data collected through surveys and interviews, (2) to disaggregate monthly and annual electricity consumption based on the data collected through the surveys in order to see the consumption by various household appliances, (3) to identify significant factors affecting the electricity consumption, (4) to compare electricity consumption of Pakistani homes with homes in other countries, and (5) to identify the current practices and awareness levels of people towards the efficient usage of electricity consumption.

Ideally, data should be collected in the various cities of Pakistan with different climatic regions. However, practically, this was a challenging task and would require considerable financial and administrative resources. Due to this limitation, the data were only collected from one city, i.e., Mirpur City. With a total population of 456,200 in 2018, the city of Mirpur is situated at 33.14° north latitude and 73.77° east longitude [11]. Electricity to Mirpur city is supplied from Mangla hydroelectric power station through a 132-kV transmission feeder with a maximum current-carrying capacity of 660 Amp. In 2018, Mirpur city had 92,977 domestic electricity connections [12]. It is anticipated that this research study will prove to be a concrete foundation for policy makers, building owners, and building designers as well as researchers working in the buildings' energy management field and will provide useful data and information for multiple desired purposes, such as devising buildings' energy codes.

2. Materials and Methods

The researchers used different methods for collecting data of buildings' energy consumption including web-based and field surveys using a questionnaire. Web-based surveys, also known as E-surveys, have gained rapid recognition in the current times. Web-based surveys are economical and a less time-consuming method of data collection, but, on the other hand, this technique has certain demerits such as a lower response rate. Further, these surveys are only successful if the respondents have internet access and sufficient knowledge of computers [13–15]. Due to these demerits, the results and findings of web-based surveys may not reflect the true results of the study. Therefore, traditional methods such as paper surveys or face-to-face interviews should be the preferred option under such circumstances [16].

In this study, a questionnaire was developed and sent to 600 employees and students of Mirpur University of Science and Technology (MUST) via emails. Only eight people (1.3%) responded and returned questionnaires filled with the requested information within the given period of 1 week. Therefore, it was decided to adopt the traditional door-to-door survey technique. Questionnaires were printed and door-to-door surveys were conducted in 600 homes. Face-to-face interviews were conducted with the house owners. This hectic exercise took about a period of 1 month (almost 20 homes per day) but resulted in an authentic and complete set of data and information required for this study. After a detailed scrutiny of the collected data, 77 questionnaires were rejected due to incomplete or missing information. The questionnaire was designed to get information about the following:

(a) Dwelling information such as age of building, type of ceiling, material used for construction, and total floor area [17,18];
(b) Availability of electricity consumption data;
(c) Demographic factors such as family size, family income, etc.;
(d) Electrical appliances, numbers, wattage, and daily usage period;
(e) Renewable energy technologies such as solar PV and solar water geyser.

The electricity consumption data were available in the form of monthly electricity bills. These were collected during the surveys. Information about household, demographic factors, renewable energy technologies, and electrical appliances was collected during face-to-face interviews with the respondents.

3. Results

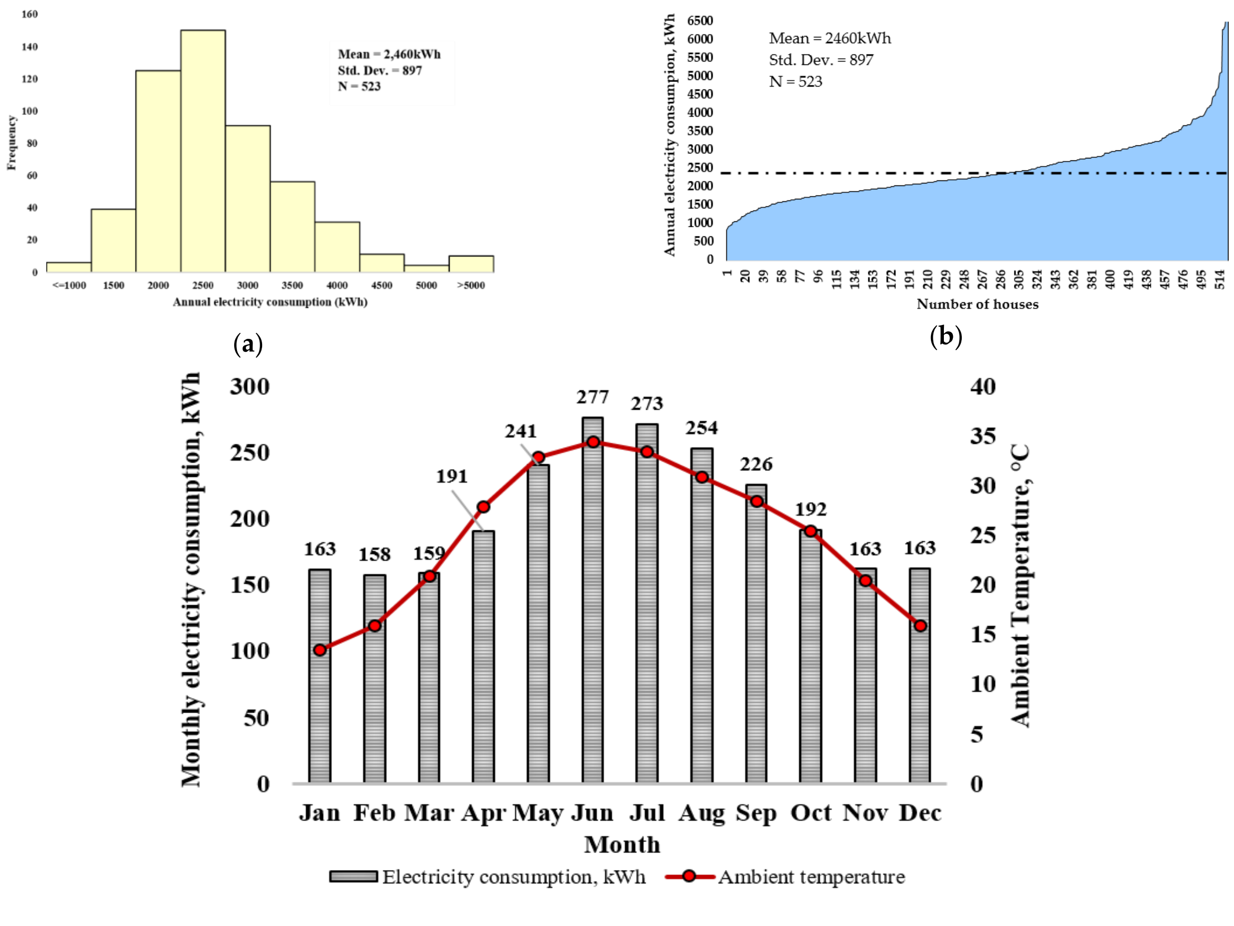
This section discusses different results that were established after detailed data analysis. First, electricity consumption data collected from electricity bills were critically analyzed and the relationship among monthly electricity consumption and ambient temperature was explored. Secondly, different household characteristics such as house type, house age, floor area, etc. and their relationship with annual electricity consumption were established and discussed. Thirdly, the effect of different demographic factors such as family size, income, etc. on the yearly electricity consumption were analyzed and discussed. Fourthly, the electricity consumption by different electrical appliances was calculated based on the data collected from the survey and standard equations. Finally, annual electricity consumption was analyzed in detail and its benchmarks in the form of kWh/m^2 and kWh/person were established and discussed for the AC and non-AC homes. Monthly profiles for the AC and non-AC houses were developed and their differences were discussed.

3.1. Annual Electricity Consumption

All electricity consumers receive electricity bills on a monthly basis. Electricity bills contain data about the monthly electricity consumption, kWh, and different taxes as well as tariff information that is applied while calculating the cost of electricity usage. Monthly consumption is calculated by subtracting the previous month's meter reading from the current meter reading records on the same day of the month. These readings are manually recorded by the staff of the electricity department. Hard copies of electricity bills were collected from all 523 homes. Electricity consumption figures from the monthly electricity bills were transferred to an MS Excel sheet and data were plotted to observe the variation. The relationship among electricity consumption and different household factors, demographic factors, and electrical appliances' factors are discussed later in this section.

Figure 2a shows the histogram of annual electricity consumption. It can be seen that 336 houses (69% of the total houses) had electricity consumption between 2000 to 3000 kWh, whereas 21% of the houses consumed more than 3000 kWh in the same year. Houses with higher electricity consumption may have had high-electricity-consuming appliances such as ACs, electrical heaters, etc. This will be further explored in the later part of this section. Only 8% of responders reported that their electricity consumption remained less than 1500 kWh. Figure 2b shows the distribution of average yearly electricity consumption in all houses. The Y-axis represents annual electricity consumption in kWh, whereas the X-axis represents the number of houses. It is apparent based on the data collected that a typical house consumed 2460 kWh on yearly basis.

The monthly electricity consumption profile is shown in Figure 2c. This profile was developed by taking the average electricity consumption for each month for all 523 houses surveyed during this study. It is apparent that summer months have higher electricity consumption due to the higher ambient temperature. This higher electricity consumption during the summer months could be attributed to the usage of cooling appliances such as ACs, air coolers, and ceiling fans. Peak electricity consumption occurs during the month of June or July, which are the hotter months in Pakistan, with the ambient temperature as high as 41 °C. Another interesting fact that is evident from the Figure 2c is that for the average consumption during the winter months (i.e., November, December, January, February, and March), the electricity consumption remained almost identical and this was mainly due to the fact that the majority of households rely on gas appliances for heating.



(**c**)

Figure 2. (**a**) Histogram of yearly electricity consumption. (**b**) Distribution of yearly electricity consumption. (**c**) Monthly electricity consumption Profile.

3.2. Household Characteristics

The household characteristics play an important role in determining the electricity consumption of a household. The impact of the main characteristics such as floor area, type of house, ownership of the house, building age, construction material, and ceiling type are discussed below.

3.2.1. Floor Area

Floor area is one of the recognized households' factors that has a positive linear relationship with a building's energy consumption. Floor area in this study represents the floor areas of all bedrooms, drawing rooms, TV lounges, and kitchens only. Data analyses showed that a typical house in Mirpur city has an average floor area of around 78.91 m^2. It is apparent from Figure 3 that bedrooms cover the major share of total floor area, 54%, with the drawing room having a share of 21%, and TV lounge of 17%, whereas the kitchen's share of the total floor area is about 8%. It was observed that majorly adopted bedroom sizes in this city are $12' \times 14'$ (51%) and $10' \times 12'$ (45%). Similarly, the typical sizes of the drawing room and TV lounge are $12' \times 14'$ or $14' \times 16'$. The Kitchen size is $8' \times 10'$.

Table 1 shows further details such as average number of room types, dimensions, and average floor area. The data analysis showed that a house in Mirpur city has an average annual electricity consumption of 32.34 kWh/$m^{2,}$ which is comparable with other countries in the south Asian region.

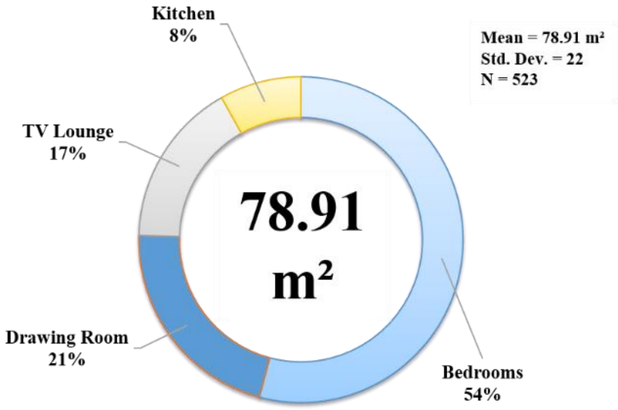


Figure 3. Percentage distribution of average floor area of a typical house in Mirpur city.

Table 1. Average floor area.

Room	Average Number	Dimensions and (Frequency)	Average Floor Area/Room
Bedroom	3.2	$12' \times 14'$ (51%) $10' \times 12'$ (45%)	13.47 m^2
Drawing Room	0.96	$12' \times 14'$ (48%) $14' \times 16'$ (43%)	18.30 m^2
TV Lounge	0.72	$14' \times 16'$ (51%) $12' \times 14'$ (42%)	17.90 m^2
Kitchen	1	$8' \times 10'$ (60%)	6.27 m^2

3.2.2. Type of House

The type of house can greatly influence a building's energy consumption [19]. The analysis of household data showed that 61% of respondents live in single-story houses and 36% live in multi-story houses, whereas only 2.29% respondents live in flats or residential plazas. This shows that living in flats is not very common in this city. The data analysis revealed that a multi-story house has an average floor area of 89 m^2 and consumes 33 kWh/m^2/year, i.e., 27% more electricity than a single-story house. This could be attributed to the fact that a multi-story house occupies a larger floor area and has a higher number of electrical appliances compared to a single-story house. On the other hand, the average annual electricity consumption in the flats was observed to be 44 kWh/m^2, i.e., nearly 37% higher than a single- or multi-story house. This higher electricity consumption in flats could be attributed to the fact that there are common areas on each floor and common parking or main entrances in the flat buildings [20,21]. The appliances in these common areas are turned on for longer hours and are not monitored properly. Another reason is that flat buildings stand taller than their neighboring buildings and are exposed to solar radiation for longer hours [22,23]. Figure 4 shows a typical house and a residential flat building in the Sector D-3 of Mirpur City.

3.2.3. Ownership of House

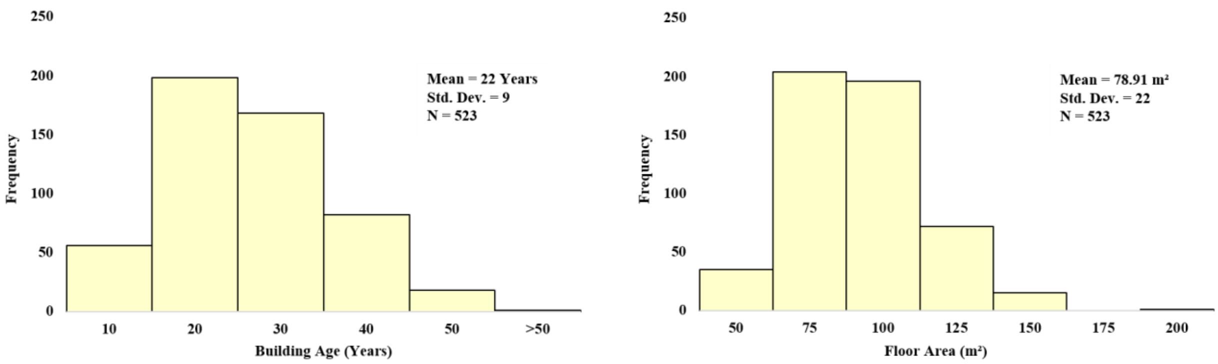
Through this study, the authors attempted to analyze the effect of building ownership on the building's annual electricity consumption. Regarding the ownership status of the building, 71% of respondents responded that they own this house, while 29% of respondents confirmed that they were living on rent. This is possibly due to the fact that there are many small industries on the outskirts of Mirpur city, people from different regions of the country have moved here to work and, therefore, they are living in the rented houses. The data analysis showed that respondents living in rented houses consume 16% more electricity on a per-square-meter basis and 4% more electricity on per-person basis. On average, a rented house consumes 2507 kWh of electricity in a year. This higher electricity consumption in rented houses could be attributed to the fact that in Pakistan mostly the tenants pay the utility bills and, therefore, the landlords have no incentive to make investments in installing energy-efficient appliances [24]. The landlords mostly resort to substandard or compromised electrical wiring and household appliances. For residential buildings where bills are included in the rent, the reason is associated with occupant behavior [25].

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

Figure 4. Typical house and residential flats in Mirpur city. (**a**) Double-story house and (**b**) Flats.

3.2.4. Building Age

Many researchers have attempted to find the relationship between a building's age and its annual electricity consumption [26,27]. Bartusch et al. [28] found a positive linear relationship, whereas Chong [29] found a negative relationship between a building's electricity consumption and its age. This factor was also analyzed in this study. As shown in Figure 5a, the average age of a residential building in Mirpur city is 22 years. In terms of annual electricity consumption, it was observed that buildings constructed before 2000 have significantly lower electricity consumption levels (31 kWh/m^2) than buildings constructed between 2000 and 2020. Buildings constructed during the 2000–2010 decade displayed an average electricity consumption of 33 kWh/m^2/yr, whereas those having an age of 10 years or less (constructed between 2010 and 2020) have an average electricity consumption of 40 kWh/m^2. This shows a negative relationship among the annual electricity consumption and the building age. The possible reason for this is that the modern buildings have more electrical appliances' provisions for the ease of living. In addition, most modern homes are also provisioned with an Uninterrupted Power Supply (UPS), electric oven, and geysers.



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

Figure 5. Histograms of (**a**) building age and (**b**) floor area of all houses.

3.2.5. Construction Material

Construction materials used in the walls and roofs have a great deal of impact on a building's energy consumption. Of the respondents, 64.6% confirmed that they have used Plain Cement Concrete (PCC) blocks without steel in their walls, while 33.4% used burned clay bricks as wall material. Regarding material used in the roof, nearly 99.4% of respondents confirmed that they had used lanterns while 0.6% had used corrugated metal sheets. It was observed that buildings where the wall material used was bricks consume 7% more electricity, i.e., 33 kWh/m^2/yr than those having PCC Concrete blocks as wall material. This is probably due to the lower thermal conductivity of the PCC blocks than the standard clay bricks.

3.2.6. Ceiling Type

Heat flow through the roof and ceiling represents a major share of the heat load of a room. Use of a false ceiling has become very common nowadays, especially in countries with very hot summer months. In Pakistan, this energy-efficiency measure has been introduced in recent years. However, due to its higher cost, it is still not welcomed by the majority of the people. In the survey, it was observed that houses with false ceilings consume 27 kWh/m^2/yr, i.e., 19% less electricity than those having standard ceilings. Table 2 presents a summary of household characteristic data collected.

Table 2. Electricity consumption of household characteristics based on frequency.

Household Characteristic	Sub-Category	Frequency	Avg. Electricity Consumption, kWh/m^2/yr
Type of Home	Single-story house	320	31
	Multi-Story house	191	33
	Flat/Residential Plaza	12	44
Ceiling type	Standard Ceiling	517	32
	False ceiling	6	27
Construction material used for walls	PCC Concrete blocks without steel	338	31
	Bricks	185	33
Construction material used for roof	Lantern	520	32
	Corrugated Metal sheets	3	35
Building ownership	Own	373	31
	Rented	150	36
Building age	≤10 years	56	40
	>10 years <20 years	198	33
	>20 years	269	30
Number of windows	1	29	28
	2	216	31
	3	184	33
	4	93	35

3.3. *Social and Demographic Factors*

Several research studies [30–33] are available where the authors have investigated the relationship among different demographic factors and electricity consumption.

3.3.1. Family Size

A number of studies [34–37] have established relationships among family size and annual electricity consumption of their houses. Data collected from 523 houses were plotted and are shown in Figure 6a. Of the respondents, 67% confirmed that they have seven or fewer than seven members, whereas 33% respondents said that they have more than seven family members. Mean family size is seven with a standard deviation of two. Families with a family size of seven or fewer consume 33 kWh/m^2/yr. or 559 kWh/person/yr., whereas a family with more than seven family members consumes less electricity, i.e., 31 kWh/m^2/yr. or 306 kWh/person/yr.

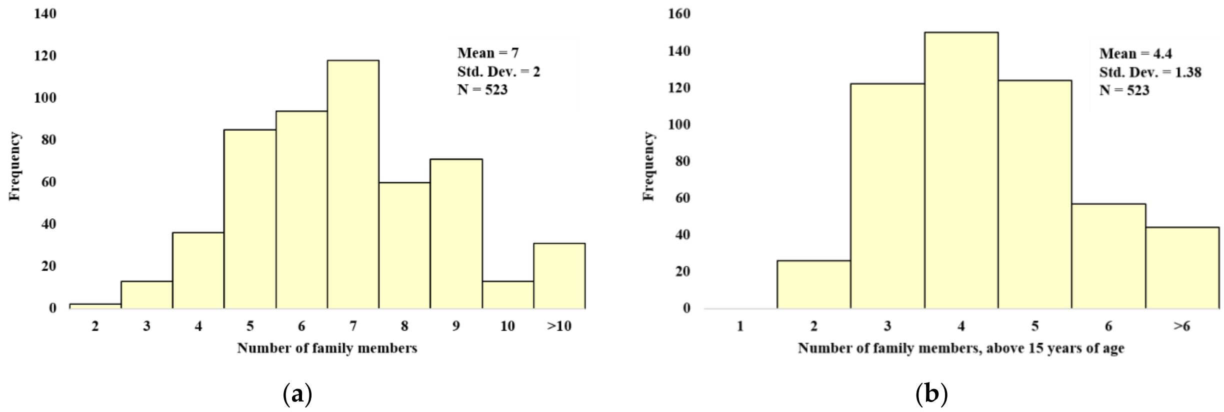


Figure 6. Histograms of (**a**) Family size and (**b**) Number of family members above 15 years of age.

3.3.2. Number of Family Members above 15 Years of Age

As shown in Figure 6b, each family has nearly four family members who are above 15 years of age. Families that have up to four family members above 15 years of age consume 445 kWh/person /yr., whereas families with more than four elders consume 28% less electricity, i.e., 347 kWh/person/yr.

3.3.3. Number of Family Members below 15 Years of Age

As evident from Table 3, each family has nearly three family members who are below 15 years of age. Families that have up to three kids consume 406 kWh/person/yr., whereas families with more than four kids consume 32% less electricity, i.e., 306 kWh/person/yr.

3.3.4. Number of Working Family Members

Data analysis, as shown in Table 3, revealed that a family with up to three working family members consumes 33 kWh/m^2/yr. and 376 kWh/person/yr., whereas families having more than three working members consume 15% more electricity, i.e., 38 kWh/m^2/yr. and 404 kWh/person/yr. This could be inferred that more working family members mean higher income and higher income means more appliances in the house and a better living style.

3.3.5. Monthly Income

A number of studies have established a relationship between the house income and its electricity. In this study, 68% of respondents refused to share their income details. Out of the remaining, 9% have a monthly income of up to 50,000 PKR and 66% have a monthly income up to 100,000 PKR, whereas 16% have income up to 150,000 PKR and 10% have monthly income of more than 150,000 PKR. Data analysis suggested that electricity consumption has a nonlinear relationship with the monthly income. Families with income up to 50,000 PKR consume 35 kWh/m^2/yr., whereas families having income up to 100,000 PKR consume 31 kWh/m^2/yr. Families having income up to 150,000 PKR or more consume 32 kWh/m^2/yr. This shows that the relationship between income and electricity consumption is somewhat nonlinear. In addition, the awareness of electricity conservation techniques varies between households.

Table 3. Electricity consumption of demographic factors based on frequency.

Demographic Factors	Sub-Category	Frequency (N)	Avg. Electricity Consumption, kWh/m^2/yr	Avg. Electricity Consumption, kWh/person/yr
Total family members	≤7	348	34	559
	>7	387	31	306
Above 15 years	≤4	298	33	445
	>4	225	33	347
Below 15 years	≤3	377	32	406
	>3	146	33	307
No. of working family members	≤3	478	32	385
	>3	45	38	404
Social class of family	Casually Social	372	31	352
	Highly Social	151	37	430
Total income of the family	Did not reply	356	33	378
	≤50,000 PKR	15	35	432
	>50,000 ≤ 100,000	136	31	364
	>100,000 PKR	16	32	406
Are you a local resident?	Yes	416	31	373
	No	107	36	382
Average number of weeks family is away	≤3	478	32	363
	>3	45	39	400
No. of full-time servants	No servant	91	31	330
	≤2 servants	414	32	377
	>2 servants	18	39	505
Have part-time servants	No	473	32	367
	Yes	50	36	376
Have cars/vehicles	No	242	32	364
	Yes	281	33	384

3.3.6. Social Class

Answering the question “how social is your family?”, 71% of respondents selected the option “Casually social”, whereas 29% of families confirmed that their family is “highly social”. This builds up a hypothesis that highly social families could have more social gatherings at their houses, which could lead to a higher electricity consumption in their houses. As presented in Table 3, this hypothesis was proven correct. It is apparent that highly social families consume 19% more electricity on a per-square-meter (37 kWh/m^2/yr.) basis and 22% (430 kWh/person/yr.) on a per-person basis when compared to the casually social families.

3.3.7. Are You a Local Resident?

Answering the question “whether you are a local resident of this city”, 416 (79.5%) residents confirmed they are residents, whereas the remaining 21.5% said that they are from other parts of Pakistan. This developed a hypothesis that usually the families who are not local residents would visit their native homes in other cities. This would have an effect on their electricity consumption. As shown in Table 3, it was observed that local families consume 16% less electricity (31 kWh/m^2/yr.) than the families who are not local residents of Mirpur city. This could be credited to the fact that most of the outsiders live in the rented flats/houses where the owners have not invested in energy efficiency and, simultaneously, the occupants do not pay too much attention to energy efficiency as well. This could be a possible reason for the increased electricity consumption by such families.

3.3.8. Number of Weeks When Family Is Away

Answering the question "how many weeks your family remains away from home in a year", 416 (79.5%) respondents confirmed that they do not leave their house, as they are local residents. Data analysis showed that local family houses consume 31 kWh/m^2/yr. Responses from outsider families were mixed. For example, the share of families who leave for less than or equal to 3 weeks consumes 32 kWh/m^2/yr., whereas families who leave for more than 3 weeks displayed annual electricity consumption of 39 kWh/m^2/yr.

3.3.9. Number of Full-Time Servants

Regarding the question "how many full time servants do you have", 9.6% confirmed that they have a full-time servant, while 53.7% said they have part-time servants. It was observed that families that have no servant at all consume 31 kWh/m^2/yr., whereas families with full-time and part-time servants consumed more electricity, i.e., 32 kWh/m^2/yr. and 39 kWh/m^2/yr., respectively. One possible justification for this could be that families who have full-time or part-time servants have higher annual incomes and, therefore, may have appliances such as ACs, UPS, hoovers, electrical geysers, etc., which consume more electricity. Secondly, the use of hoovers by the servants could also be a possible reason for this increased electricity consumption in such houses.

3.4. Electrical Appliances, Usage, and Electricity Consumption

The questionnaire was designed in such a way to acquire further information about the electrical appliances possessed by the household and their respective usage. A correlation was made between electrical appliances possessed and their electricity consumption to create household categories.

3.4.1. Ownership of Appliances

Figure 7 shows different appliances and the percentage of houses having these appliances. The analysis of collected data showed that almost every house in Mirpur has a refrigerator, a TV, a room cooler, a washing machine, an electric iron, and six ceiling fans. One in every two homes has a UPS. Out of every 10 homes, every six homes have an electric geyser, a washing machine and dryer, and a water pump, whereas out of every 10 homes, every three homes have a pedestal fan and an electric cooker. Out of every 10 homes, nearly four homes have AC and two homes have a water dispenser.

The data were collected about the daily usage of all these appliances and these data were used for calculating yearly electricity usage by these appliances. Some additional questions were asked to the respondents regarding the ACs such as cooling capacity of the AC and the set temperature at which respondents run their AC, as these factors both have direct relationships with the electricity consumption by the ACs.

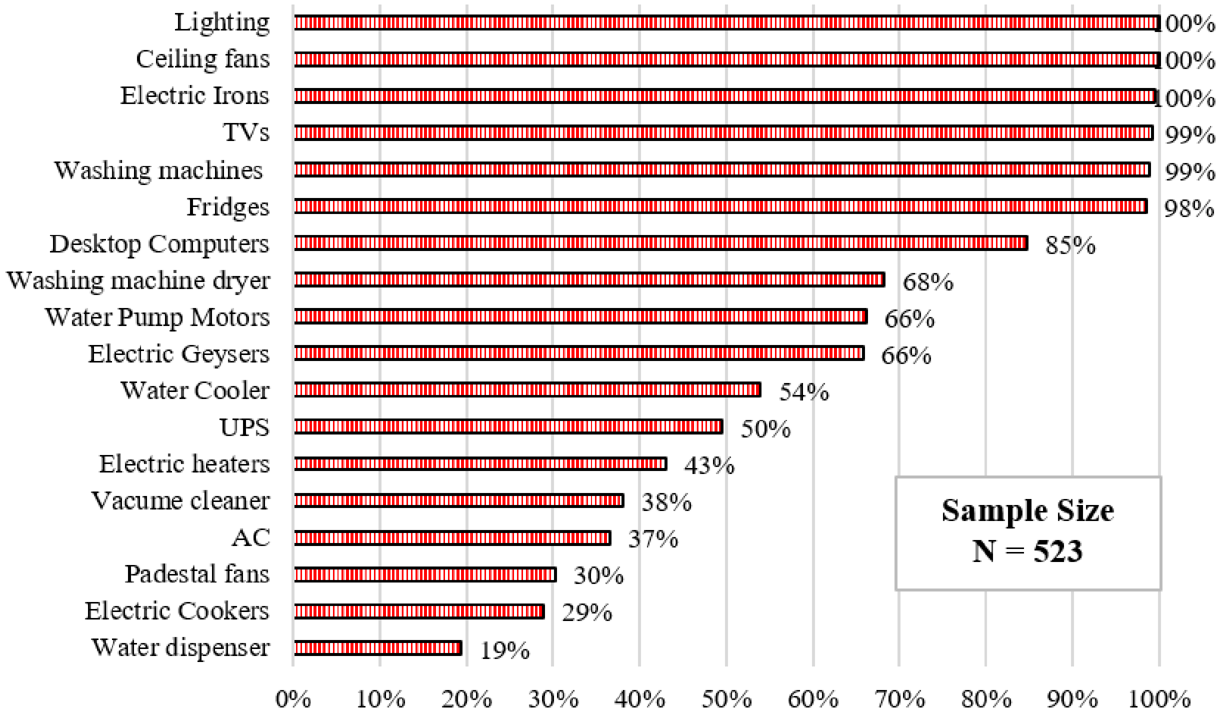


Figure 7. Percentage of appliance ownership in a typical household.

3.4.2. Correlation among Different Appliances

The correlation between different appliances could be helpful in categorizing different houses. Table 4 presents the Pearson correlation (R) between different appliances. It is apparent that a house that would have an AC will also have a UPS, whereas a house that has an electrical geyser would also have an electric cooker and electric heaters.

Table 4. Correlation of household electrical appliances.

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}
Clothes dryer, x_1	1.00	0.13	0.15	0.10	0.28	0.16	0.18	0.25	0.06	0.08	0.15
Water pump, x_2	0.13	1.00	0.18	0.29	0.27	−0.01	0.15	0.28	0.00	0.21	0.12
Electric geyser, x_3	0.15	0.18	1.00	0.17	0.36	0.46	0.37	0.32	0.08	0.41	0.18
Air cooler, x_4	0.10	0.29	0.17	1.00	0.30	0.02	0.14	0.03	0.01	0.25	0.13
UPS, x_5	0.28	0.27	0.36	0.30	1.00	0.28	0.36	0.47	0.04	0.27	0.21
Electric heater, x_6	0.16	−0.01	0.46	0.02	0.28	1.00	0.25	0.20	0.17	0.28	0.14
Vacuum Cleaner, x_7	0.18	0.15	0.37	0.14	0.36	0.25	1.00	0.32	0.12	0.28	0.17
AC, x_8	0.25	0.28	0.32	0.03	0.47	0.20	0.32	1.00	−0.01	0.18	0.30
Pedestal fan, x_9	0.06	0.00	0.08	0.01	0.04	0.17	0.12	−0.01	1.00	0.23	0.01
Electric cooker, x_{10}	0.08	0.21	0.41	0.25	0.27	0.28	0.28	0.18	0.23	1.00	0.12
Water dispenser, x_{11}	0.15	0.12	0.18	0.13	0.21	0.14	0.17	0.30	0.01	0.12	1.00

3.4.3. Correlation of Different Appliances with Monthly and Yearly Total Electricity Consumption

The correlation between different appliances and their monthly and yearly total electricity consumption is also helpful in categorizing different houses. Table 5 presents this correlation between different household appliances. From Table 5, it is evident that the AC is the most influential appliance that could affect the house's annual electricity consumption. The UPS shows the second highest correlation coefficient with the annual electricity consumption. Higher correlations of AC and UPS with the monthly electricity consumption in the months of April–October clearly indicate that these two pieces of equipment are highly energy intensive compared to other appliances and are correlated with the appliances such as electric geyser, hoover, and dispenser, which also present a strong relationship with the electricity consumption of a house. Therefore, it was assumed that if a house has an AC, it would also have a UPS, electric geyser, electric heater, hoover, electric cooker, and water dispenser, whereas in a non-AC house will not have these pieces of equipment but may have a UPS.

Table 5. Correlation (R) of household appliances with monthly and annual electricity consumption.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
x_1	0.19	0.22	0.20	0.25	0.27	0.28	0.31	0.27	0.31	0.26	0.24	0.25	0.35
x_2	0.13	0.12	0.09	0.26	0.31	0.28	0.29	0.25	0.18	0.11	0.08	0.14	0.28
x_3	0.38	0.36	0.34	0.34	0.33	0.32	0.32	0.30	0.19	0.20	0.20	0.31	0.40
x_4	0.07	−0.02	0.00	0.10	0.22	0.20	0.19	0.16	0.15	0.03	−0.03	−0.01	0.15
x_5	0.25	0.24	0.26	0.37	0.44	0.40	0.44	0.38	0.37	0.25	0.27	0.26	0.46
x_6	0.37	0.35	0.26	0.22	0.18	0.19	0.15	0.20	0.13	0.19	0.22	0.26	0.29
x_7	0.29	0.29	0.30	0.32	0.37	0.32	0.33	0.30	0.27	0.26	0.20	0.23	0.40
x_8	0.28	0.29	0.32	0.46	0.58	0.59	0.65	0.61	0.53	0.41	0.30	0.25	0.64
x_9	0.06	0.08	0.08	0.07	0.06	0.03	0.06	0.08	0.09	0.08	0.06	0.02	0.08
x_{10}	0.08	0.07	0.04	0.14	0.22	0.21	0.21	0.21	0.13	0.08	−0.04	−0.02	0.18
x_{11}	0.28	0.18	0.24	0.28	0.29	0.31	0.32	0.32	0.27	0.23	0.19	0.16	0.36

3.4.4. Usage Patterns of Different Appliances

In the absence of submeters, it was hard to disaggregate the total household monthly electricity consumption into appliance-wise electricity consumption. Therefore, it was decided to follow a conventional approach of estimating electricity consumption of different appliances on a monthly basis. This was achieved through collecting information from the respondents about the usage hours of different appliances during different months of the year. The data in Table 6 show the average daily usage hours, watt ratings, and yearly electricity consumed by different appliances in the form of kWh. Regarding the use of AC, the majority of respondents confirmed that they use it only during the summer months (May to September), whereas ceiling fans remain operational from April to October. Houses where there is no AC use water coolers during the summer months. The average weekly use of washing machines is 7 h, i.e., 1 h per day. The yearly electricity consumption was calculated as follows:

$$Yearly\ Electricity\ Consumption = Annual\ usage\ hours \times (Watt \div 1000) \times 0.75 \quad (1)$$

where the value "0.75" represents the scaling factor, showing that appliances run at 75% capacity. It is clear that AC and UPS are the two major electricity-consuming appliances and their presence in a house means higher yearly electricity consumption in that house.

Table 6. Daily usage hours, watt ratings, and yearly electricity consumption of different appliances.

Appliance	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total Hours	Watt	kWh
Air Conditioner	0	0	0	0	5	7	8	8	5	0	0	0	1011	1200	910
Bedroom Fan 1	0	0	0	9	4	4	4	4	4	8	0	0	1130	100	85
Bedroom Fan 2	0	0	0	9	4	4	4	4	4	8	0	0	1130	100	85
Kitchen Fan	0	0	0	6	6	6	6	6	6	6	0	0	1284	100	96
TV Lounge Fan	0	0	0	8	8	8	8	8	8	8	0	0	1712	100	128
Drawing Room Fan	0	0	0	1	1	1	1	1	1	1	0	0	214	100	16
Other Fan	0	0	0	1	1	1	1	1	1	1	0	0	214	100	16
Water Cooler	0	0	0	7	12	12	12	12	10	8	0	0	2234	140	235
Microwave Oven	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	91	1200	82
UPS	2	2	2	4	4	4	4	4	4	3	2	2	1127	1000	845
Washing Machine	1	1	1	1	1	1	1	1	1	1	1	1	365	150	41
Bedroom 1 Light	4	4	4	4	4	4	4	4	4	4	4	4	1460	30	33
Bedroom Light 2	4	4	4	4	4	4	4	4	4	4	4	4	1460	30	33
Kitchen Light	4	4	4	4	4	4	4	4	4	4	4	4	1460	30	33
TV Lounge Light	8	8	8	8	8	8	8	8	8	8	8	8	2920	30	66
Drawing Room Light	1	1	1	1	1	1	1	1	1	1	1	1	365	30	8
Other Light	6	6	6	6	6	6	6	6	6	6	6	6	2190	30	49
Fridge	3	3	3	5	8	8	8	8	8	5	3	3	1982	250	372
TV	6	6	6	6	6	6	6	6	6	6	6	6	2190	140	230
Iron	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	183	1000	137
Laptop	3	3	3	3	3	3	3	3	3	3	3	3	1095	140	115
Water pump	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	183	1000	137
Vacuum Cleaner	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	183	1000	137

3.4.5. Categorization of Houses Based on Energy-Intensive Appliances

Based on the fact that the AC and UPS are the two major electricity-consuming appliances, all 523 houses were divided into four different categories, which are as follows:

1. Category—1. Non-AC House without UPS
2. Category—2. Non-AC House with UPS
3. Category—3. AC House without UPS
4. Category—4. AC House with UPS

The possession of different electrical appliances and actual and estimated electricity consumption in all four different category houses is presented in Table 7.

Table 7. Possession of electrical appliances in different house categories.

Electrical Appliances	House Category			
	Category-1	**Category-2**	**Category-3**	**Category-4**
	Non-AC House without UPS	**Non-AC House with UPS**	**AC House without UPS**	**AC House with UPS**
Lights	✔	✔	✔	✔
Ceiling fans	✔	✔	✔	✔
Electric Irons	✔	✔	✔	✔
TVs	✔	✔	✔	✔
Washing machines	✔	✔	✔	✔
Fridges	✔	✔	✔	✔
Desktop Computers	✔	✔	✔	✔
Washing machine and dryer	✔	✔	✔	✔
Water Pump Motors	✔	✔	✔	✔
Water Cooler	✔	✔	X	X
UPS	X	✔	X	✔
Vacuum cleaner	X	X	✔	✔
AC	X	X	✔	✔
Actual average electricity consumption, kWh/year	1974	2409	2487	3207
Calculated average electricity consumption, kWh/year	1996	2841	2808	3654
Difference, %	1.1%	17.9%	12.9%	13.9%

It can be observed that there is a difference of 1.1% for category-1 house, 17.9% for category-2 house, 12.9% for category-3 house, and 13.9% for category-4 house (average difference = 11.45%) between actual and estimated electricity consumption. This difference is due to the fact that different houses may have different ratings, efficiencies, and usage hours of different appliances. It is important to mention here that the difference between actual and estimated electricity consumption for all four categories is within an acceptable range and, therefore, this survey-based methodology adopted for appliance-wise disaggregation of household electricity consumption was quite robust. Due to the acceptable difference between actual and estimated electricity consumption, in the next section, the actual electricity consumption data were used and were disaggregated for appliance-wise electricity consumption.

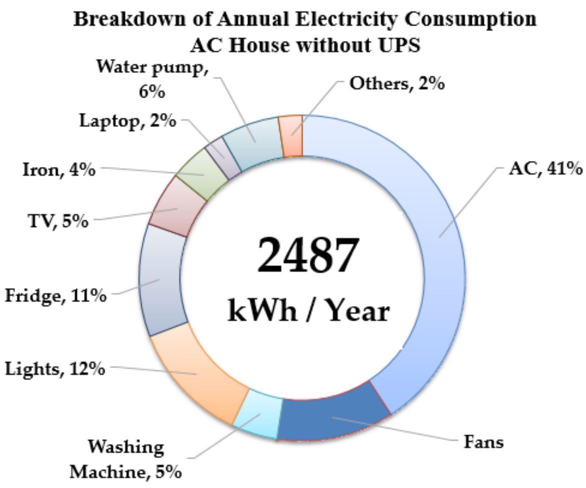
Electricity Consumption of Non-AC House with and without UPS (Category-1 and Category-2 Houses)

The data analysis revealed that the difference in annual electricity consumption of non-AC houses with and without the UPS was significant. The electricity consumption of the non-AC house without UPS was 1974 kWh/Year, as shown in Figure 8a. The most significant contributors of the electricity consumption for non-AC houses without UPS were the fans, which utilized 22% of the total consumed electricity. The electricity consumption of non-AC houses with UPS was 2409 kWh/Year, i.e., 435 kWh/Year (22%) higher compared to non-AC houses without UPS, as shown in Figure 8b. The interesting thing to observe here is that the major contributors of electricity consumption in this case were the fans and the UPS, consuming 18% each. This gives a very clear indication of the shift in electricity consumption due to the use of a UPS. In addition, a similar trend was observed for monthly electricity consumption of the non-AC houses with and without UPS, as shown Figure 8c. The electricity consumption for both cases was on the rise for the months from April to October.

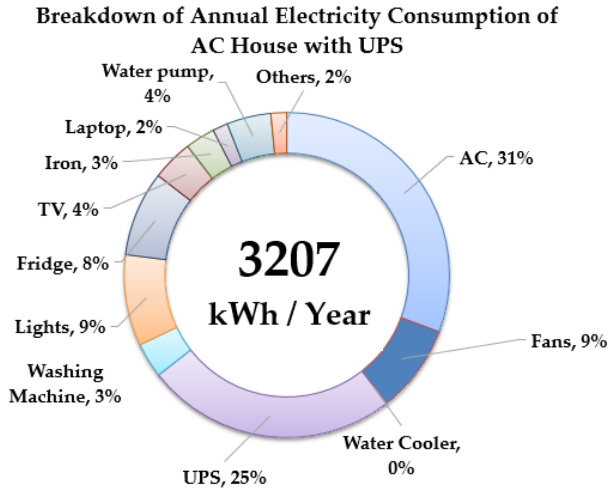
Figure 8. (**a**) Breakdown of Annual Electricity Consumption of a Non-AC House without UPS, (**b**) Breakdown of Annual Electricity Consumption of a Non-AC House with UPS (**c**) Monthly electricity consumption of non-AC houses with and without UPS.

Annual Electricity Consumption of AC House with and without UPS

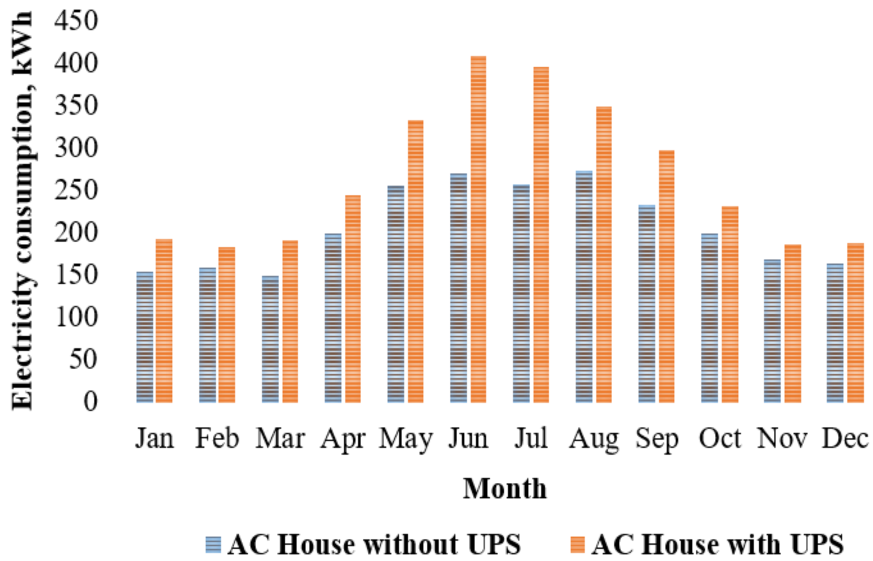
Similar to the earlier subsection, the data collected revealed that the difference in electricity consumption of AC houses with and without the UPS was quite significant. The electricity consumption of the AC house without UPS was 2487 kWh/Year as shown in Figure 9a. The most significant contributors of the electricity consumption for AC houses without UPS were the ACs, which utilized 41% of the total consumed electricity. The electricity consumption of AC houses with UPS was 3207 kWh/Year and this was 720 kWh/Year (29%) higher compared to AC houses without UPS, as shown in Figure 9b. The interesting thing to observe here is that the major contributors of electricity consumption in this case were the ACs and the UPS, consuming 32% and 22%, respectively. The figures below present a very clear indication of the increase in electricity consumption due to the use of the UPS. In addition, a similar trend was observed for monthly electricity consumption of the AC houses with and without UPS, as shown Figure 9c. The electricity consumption for both cases was on the rise for the months from April to October.



(a)



(b)

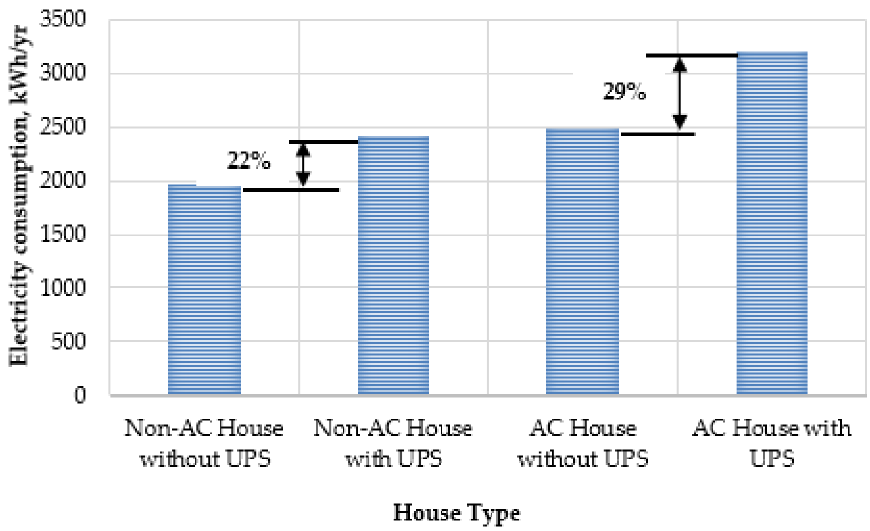


(c)

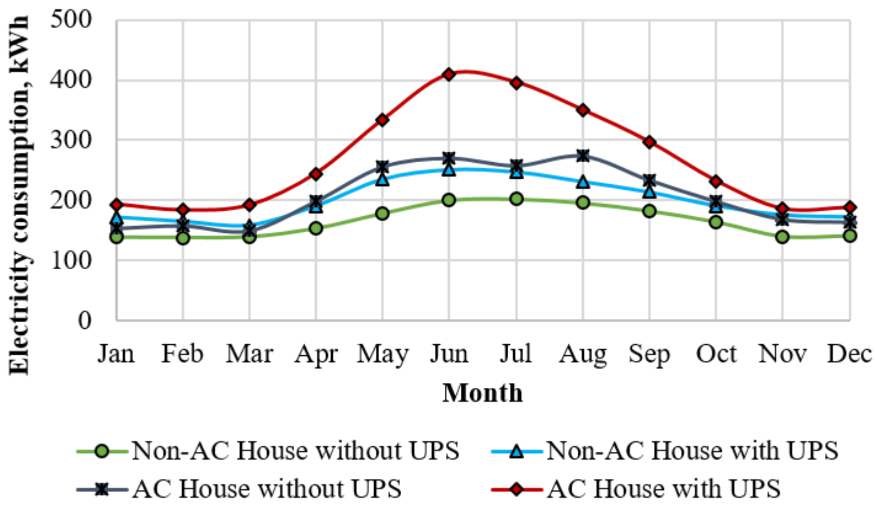
Figure 9. (**a**) Breakdown of Annual Electricity Consumption of an AC House without UPS, (**b**) Breakdown of Annual Electricity Consumption of an AC House with UPS (**c**) Monthly electricity consumption of AC houses with and without UPS.

Comparison of Electricity Consumption by AC and Non-AC Homes with and without UPS

Figure 10 shows the annual electricity consumption and monthly electricity consumption profile of all four categories of houses. It is apparent that the presence of the UPS in a non-AC house results in 22% higher electricity consumption, whereas in an AC house, UPS presence means 29% higher electricity consumption, leading to an increased electricity bill. This is mainly due to the fact that the UPSs are active on the main electricity for the whole day and are operational even when the batteries are fully charged. This trend is in line with the study conducted on charging and discharging of different types of UPSs [38]. The study concluded that the UPS causes great losses to the overall electricity consumption and the quality of the UPS is also an important factor. The lack of regulations on UPS quality and the abundance of substandard inefficient UPSs in the market greatly adds to this. Another study [39] backed the above findings and further investigated the impact of the UPS on the distribution transformers, conductors, and the fan's life. Overall, it is an interesting finding that a UPS consumes as much electricity as an AC.



(**a**)



(**b**)

Figure 10. (**a**) Yearly electricity consumption of AC and non-AC houses with and without UPS. (**b**) Monthly electricity consumption of AC and non-AC houses with and without UPS.

4. Discussion

This section discusses the challenges faced during the data collection and analysis phases, the lack of awareness among the public regarding electricity conservation, a comparison of electricity between different developing countries, and, finally, some recommendations are proposed to improve household electricity consumption.

4.1. Challenges Faced

The local electricity department was reluctant to share electricity consumption data of its consumers due to privacy issues, whereas people did not respond well to e-surveys and e-forms. Therefore, the authors had to collect electricity data and other household information by visiting people door to door. Among various challenges faced by the authors during the data collection exercise was reluctance of households to share their electricity bills and building-related information. Most households were cooperative and convinced that the results of the study will be useful for the public at large. Collection of hard copies of electricity bills and then transferring consumption data into excel sheets for further analysis proved to be a very time-consuming activity. Data from electricity bills showed aggregated monthly consumption, and, therefore, it was hard to disaggregate this consumption without having sufficient knowledge of household appliances, their ratings, and duration of usage. This shortcoming forced the authors to conduct face-to-face interviews and use survey forms to collect information regarding socioeconomic, demographic, and building characteristics, and household appliances.

4.2. Awareness about Energy Conservation, Smart Meters, Appliance Ratings, and Renewables

The authors are of the opinion that people lack awareness about energy conservation measures and use of renewable technologies, use of smart meters, and information about appliance ratings and their impact on overall household electricity consumption. Lack of incentives from the government to encourage people to use star-rated appliances is another key factor resulting in higher electricity consumption. However, it was very encouraging to see people showing interest to understand the role the above mentioned can play in energy conservation leading to reduction in costs associated with electricity usage.

4.3. Comparison of Electricity Consumption with Previous Studies and Other Countries

In Figure 11, a comparison of household annual electricity consumption in Pakistan along with other developing countries, as mentioned in [9], is shown. It is interesting to note that a house in Pakistan consumes almost the same amount of electricity as a house in Thailand. Higher electricity consumption in the EU and world could be attributed to the stronger economies of countries such as the US, UK, and other developed countries.

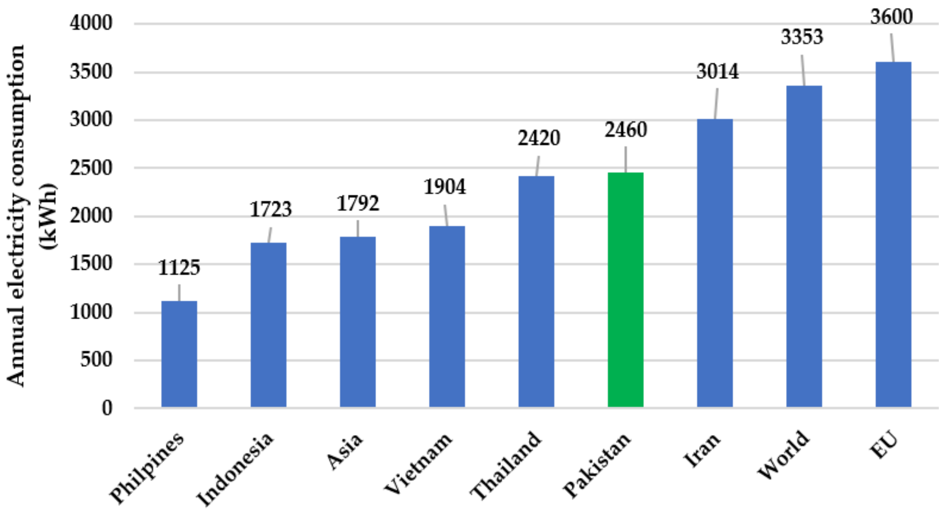


Figure 11. Comparison of residential buildings' average annual electricity consumption [9].

4.4. Recommendations

The detailed study and interaction with the people provided lots of avenues for useful recommendations for regulating household electricity consumption in the developing countries. As a first step, it is very important to raise awareness about electricity conservation measures and their impact on the electricity-associated costs. This can be achieved through government intervention in providing incentives for the use of solar and other renewables, and, similarly, providing subsidies on the star-rated appliances. The government can also regulate the building codes to ensure efficient electricity consumption. This is possible by using building insulation, energy-friendly building materials, false ceilings, and energy-efficient building designs. It is also important to highlight that the conventional ACs and locally manufactured UPSs are the two major electricity-consuming appliances. It is recommended to use DC-inverter ACs to replace conventional ACs and for low-quality UPSs to be replaced by good-quality and branded UPSs. With the proliferation of wireless technologies and the Internet of Things (IoTs) in developing countries, it is recommended to promote the use of smart meters, which can enable people to monitor and control their real-time electricity consumption through various applications.

5. Conclusions

For the first time, a survey-based study attempted to unlock the details of annual electricity consumption of residential buildings of Pakistan. Data related to the annual electricity consumption, house type, floor area, and different demographic factors were collected from 523 houses in the Mirpur City of Pakistan in 2019. The data were thoroughly analyzed, and the relationship of different household characteristics, possession of different electrical appliances, and different demographic factors was established with the annual electricity consumption of the houses. In addition to this, the houses were categorized into four different categories and the effect of having an UPS on the annual electricity consumption of AC and Non-AC houses was investigated. The followings are our main findings.

(1) The average floor area is 78.91 m^2 with an average annual electricity consumption of 32.34 kWh/$m^{2,}$ which is comparable with other countries in the south Asian region. People living in rented houses consume more electricity (nearly 16% higher) than those who own their houses. A multi-story house consumes 33 kWh/m^2/year, i.e., 27% more electricity than a single-story house, whereas the average annual electricity consumption in the flats was observed to be 44 kWh/m^2, i.e., nearly 37% higher than a single- or multi-story house. A negatively linear relationship among the building age and its electricity consumption was observed. Brick-built houses consume 7% more electricity, i.e., 33 kWh/m^2/yr more than those having PCC Concrete blocks as wall material. The use of a false ceiling can result in a 19% reduction in the annual electricity consumption.

(2) The average family size is seven, with four adults and three kids. The average electricity consumption is 559 kWh/person/yr. A family having up to three employed members consumes 376 kWh/person/yr., whereas families having more than three employed members consume 15% more electricity, i.e., 404 kWh/person/yr. A nonlinear relationship between family income and electricity consumption was observed. The social class of the family has a direct influence on the electricity consumption. A highly social family consumes 22% more electricity than a casually social family. Families that have full-time and part-time servants consume more electricity.

(3) Almost every house in Pakistan has a refrigerator, a TV, a room cooler, a washing machine, an electric iron, and six ceiling fans. One in every two homes has a UPS. Out of every 10 homes, every six homes have an electric geyser, a microwave oven, and a water pump, whereas out of every 10 homes, every three homes have a pedestal fan. A non-AC house with UPS consumes 22% more electricity compared to a non-AC house without UPS. In an AC house without UPS, the share of AC is 41% in total electricity consumption, whereas in an AC house, UPS presence means 29% higher electricity consumption,

leading to an increased electricity bill. There must be some standards for ensuring good-quality UPSs.

(4) Based on this study, residential buildings in Pakistan consume almost the same electricity on an annual basis as in Thailand; however, compared to the average electricity consumption of Asia's residential sector, Pakistani houses consume 37% more electricity consumption on a yearly basis. This could be attributed to the variation in income per capita.

In a nutshell, it is evident that the buildings' sector in Pakistan consumes as high as 55% of its available electricity. However, there are no published studies on its residential energy consumption and, therefore, it is hoped that this study will provide a foundation for further research in this much needed area. It is anticipated that the results of this study will be helpful for devising effective energy policy and energy codes for the residential buildings' sector in Pakistan. Appliances such as a UPS and AC are the major electricity-consuming appliances and there must be regulations for these two categories of appliances. The policy document must promote energy conservation and energy efficiency measures. Development and implementation of effective building codes/policies are, therefore, indispensable for controlling future energy consumption in Pakistan's residential building sector. It is also hoped that this study will help the policy makers in the forecasting of future energy demand.

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