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Analysis of Energy Consumption Based on Household Appliances in Jodhpur, India

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Abstract**—**Energy is the basic element for any country's economic development. India is one of the most populated countries, and is dependent on fossil fuel and nuclear-based energy generation. The energy sector faces huge challenges and is dependent on the import of energy from neighboring countries to fulfill the gap in demand and supply. India has huge setbacks for efficient energy generation, distribution, and consumption, therefore they consume more quantity of energy to produce the same amount of Gross Domestic Product (GDP) compared to the developed countries. Technology and technique use, availability, and affordability in the various sectors are varying according to their economic status. In this paper, an attempt is made to quantify the domestic electrical energy consumption in Jodhpur, India. Survey research methods have been employed and stratified sampling technique-based households were chosen for conducting the investigation. Pre-tested survey schedules are used to investigate the grassroots level study. The collected data are analyzed by employing statistical techniques. Thereafter, a multiple regression model is developed to understand the functions of total electricity consumption in the domestic sector corresponding to other independent variables including electrical appliances, age of the building, household size, education, etc. The study resulted in identifying the governing variable in energy consumption at the household level and their relationship with the efficiency of household-based electrical and energy appliances. The analysis is concluded with the recommendation for optimizing the gap in peak electrical demand and supply in the domestic sector.

Keywords**—**Appliance, consumption, electricity, households.

I. Introduction

POWER and energy play a pivotal role in building the nation's economy. Being the third-largest economy of the world, India is also the third-largest energy consumer after the USA and China. India's two-third population resided in villages and has shown a significant increase in energy consumption in past trends. The adaptation of renewable energy technology in infrastructure and advancement in household appliances has tremendously increased energy consumption such as several authors forecasted the energy demand will double in 2040 [1], [4], [7]. The residential and commercial sector has a respective energy consumption of 25% and 75% of the total 33% of total energy consumption within the building sector in India. Lighting appliances such as incandescent bulbs are amongst the most favored and popularly used for their lowest setup cost compared to CFL, LED, and tube light fixtures. Similarly, the lower and middle-income households opt for cheaper household appliances and compromise with star-rated appliances, efficient technology, and usages technique [9]. Urban area prefers LPG and electronics appliance for cooking purpose whereas in rural areas dependencies over kerosene, wood, coal, and LPG are observed [6]. Per-capita electricity consumption is 4 times higher in an urban area than in rural areas [5]. Dependence on traditional electricity sources is higher in rural areas compared to urban areas [7], [2]. In developing countries like India, rapid urbanization spread from the urban area towards village has led to increasing in household income and energy consumption within a decade; similar trends were also observed in Taiwan before 20th century [3]. The present study analyses the trends and significance amongst energy consumption, household income, and household appliances.

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II. Study Area at a Glance

Jodhpur City is the administrative headquarters of the district and regional center of the state Rajasthan, India. Jodhpur city sited between 26 00' and 27 37' North latitudes and 72° 55' to 73°52' East longitudes. Jodhpur city is also known as Sun City of the Rajasthan state and developed as a smart city under the National Smart Cities Mission by the Government of India. The area of the district is 22,850 Sq.km, which is 6.59% of the area of the State [10]. Jodhpur is majorly habituated by the Hindu religion, which consists of cast Brahmin, Rebari, Choudhari, Jangid, etc., and remaining 13%, 3.70% and 1.3% are respectively are Muslim, Jain and, Christian (including Sikh and others). The city is the origin of Maarwad's social and cultural values. In 1901, the population of the city was 79,109, and it has increased to 1,033,918 in 2011. Its Urban/Metropolitan population is 1,137,815 of which 599,332 are males and 538,483 are females. Higher-level population growth of an average of 30% is expected in the next two decades. It consumed 13813 lakh units of electrical energy in 2015 [9], [10]. Domestic energy consumption in Jodhpur city has increased 61.15% from 2010 to 2015, i.e. in 2010 it was 2950 lakh units, and in 2015, it was 4754 lakh units as presented in Table I.

III. Population and Household Size

The majority of households are with a family size of 5-8 members per family, and the average household size is approx.6 people per household. The primary survey data show that the 149 households in the low-income group (≤ 4 Lakh) have 822 people, 61 households in the medium income group (4 L-8 L) have 368 people, and 45 households in the higher-income group (8 Lakh+) have 280 people.

TABLE I
NUMBER OF CONSUMERS AND TOTAL ELECTRICITY CONSUMPTION (LAKH UNIT) IN JODHPUR CITY [6]

Sr.	Sector	2010		2015	
		Consumer	Consumption (lakh kWh)	Consumer	Consumption (lakh kWh)
1	Domestic	167139	2950	241062	4754
2	Non- Domestic	35474	1194	41224	2211
3	Industrial	5697	2993	7128	4593
4	Agricultural	568	33	572	112
5	Street Lighting	528	576	634	956
6	Public Water	136	351	245	348
7	Mixed	107	1116	194	840
8	Total	209648	9213	291059	13813

TABLE II
INCOME WISE AVERAGE HOUSEHOLD SIZE AND POPULATION

Sr.	Income Group	Household(HH)		Population		Avg. Size/HH
		Nos.	Percent (Pct.)	Nos.	Percent	Nos.
1	≤ 4 Lakh	149	58%	822	56%	5.52
2	4 L-8 L	61	24%	368	25%	6.03
3	8 Lakh+	45	18%	280	19%	6.22
4	Total	255	100%	1470	100%	5.76
5	The average family size is approx. 6 Person/ Household					

Majority of household belongs to Hindu religion, and it is 75% of the surveyed households, and the remaining 25% consist of Muslim, Sikh, and Christian religion. The trend of joint family is decreasing as the ratio between nuclear and joint family is only 5:1. Out of 255 households, 70% of households have a maximum of 2 earning members and the lower-income group has 70% of it. Total earning members consist of 518 people of the surveyed 255 households. The majority of the population is between the age group 26-40, and the age group of 16-60 is 60% of the 1470 people. The numbers of the infant are very less, and per family children of age 0-5 is maximum of 2 children. The sex ratio is 54% male and 46% female, and the marital ratio is 58% married and 42% are unmarried members of the 1470 population of surveyed households. In education qualification, the majority of them (60%) lies in the primary and secondary level, whereas the professional diploma degree and PhD degree holders are only just 2%. The population of the student is more compared to occupation strength. Around 26% of people have self-business and the strength of the retired person is only 2% of the total of 960 persons. Population classification of the surveyed household is presented in Table II [8].

IV. ENERGY CONSUMPTION IN HOUSEHOLD FOR DOMESTIC APPLIANCES

Domestic energy consumption in a household is a function of electrical and other appliances that directly or indirectly influence the overall energy consumption. It is very essential to consider the capacity, efficiency, numbers, usages duration, frequency, lifetime, and energy-saving standards while studying the overall household energy consumption. A similar effort has been done to estimate the household level of domestic consumption through various appliances.

The majority of households use tube light, 44%, whereas the use of CFL is 37% which is more than incandescent bulbs. The popularity of LED light is becoming popular due to cheap variants of such lighting in each income group. It is seen that 13% incandescent bulb consumes 24% of electricity whereas 37% of CFL consumes only 20% of electricity. This represents that households in Jodhpur prefer the use of CFL over incandescent bulbs. Use of AC is more in the higher income group as window AC is 44% and split AC is 25% in combined strength of lower and medium-income groups. The use of room heaters in households is 7% which contributes 11% to electricity consumption by HVAC appliances. The majority of consumption is influenced by ceiling fans which alone consume 34% of electricity with 59% of total HVAC appliances. Usages and consumption with the washing machine are not much, since washing is still preferred with traditional ways. Fridge consumes 86% of total electricity as consumed by general appliances. Preference for the induction stove is most popular in the high-income group which is 50% and 50% is combined in lower and medium-income groups. Preference to induction stove for cooking purpose is giving rise to electricity consumption, as alone induction stoves consume 74% of the total electricity consumed under cooking appliances category. The use of pressure cookers is 56% in the lower-income group, 24% in the medium group, and 19% in the higher income group. Smart and normal mobile appliances are dominating 31% more than the number of televisions. The electricity consumption by television is major as it is 77% and mobile appliances have consumption of 2.5% of the total consumption of entertainment appliances. The use of exhaust fans is rare in newly constructed households. Water pumps are accounted for 93% of electricity consumption amongst other appliances. Handheld appliances for daily use such as vacuum cleaner, hairdryer, sewing machine, electric iron consume 6%, 10%, 5% and 78% electricity consumption. Use of hairdryer and a vacuum cleaner is major in the high-income group Water heating appliances, geyser and immersion rod, have approximately equal preferences and both strengths are 51% and 49% respectively but the energy consumed by immersion rod is 60% more than the consumption by a geyser. This shows that immersion rod capacity, frequency, and duration of use are more and efficiency is less compared to geysers. Since apartment numbers are only 6% of total surveyed housing, only 6% of households have lift as emergency power sources only 22% of households have UPS systems.

A survey is also carried out to calculate the overall electricity consumption for households. General household

appliances play a major role in consumption profile, and peak load demand in the settlement. It describes that overall electricity consumption is varying from various categories and it is 10% form star–rated lighting appliances, 46% of form star-rated HVAC appliances, 18% form star-rated general appliances, 5% form star-rated cooking appliances, 10% form star-rated water heating appliances, 6% form star-rated entertainment appliances, 4% form star-rated other appliances of the total 12.46 lakh units electricity consumption per year. The electricity consumption from space HVAC accounted for the highest, which is about 50% of the total electricity consumption.

Electricity utility annual bill is counted for each household according to the date of the specified charge for various unit consumption group rates. Households observed under billed quantity per month are 5% with bill ≤ 150 kWh/month, 37% with bill 150-300 kWh/month, 33% with 300-450 kWh/month and 25% with 450+ kWh/month. Since 50 unit billed quantity is accounted under the fixed bill and remaining categories are 95% of the total households, this factor can be used to plan discount/subsidy for integrating solar energy appliances. Per capita energy consumption is found as 1405.12 (49%) kWh/ person/year for the higher income group, 771.68 (27%) kWh/ person/year for the middle-income group, and 692.12 (24%) kWh/person/year for the lower-income group. Thus, the average 2.36 units/person/day or 13.58 units/ household/day is consumed in the Jodhpur city system, and the household appliances wise electricity consumptions are presented in Table III with their respective income groups [8].

TABLE III
ELECTRICITY CONSUMPTION (KWH/YEAR) OF DOMESTIC APPLIANCES IN HOUSEHOLDS

Sn.	Appliances	1		2		3		4		5	
	Income Group	Lighting		HVAC		General		Cooking		Water Heating	
		kWh	Pct.	kWh	Pct.	kWh	Pct.	kWh	Pct.	kWh	Pct.
1	≤ 4 Lakh	65212	53%	236864	41%	115221	50%	16605	26%	67230	56%
2	4 L-8 L	30228	25%	119804	21%	58910	26%	15093	24%	27000	22%
3	8 Lakh+	27764	23%	220837	38%	55471	24%	31500	50%	26280	22%
4	Total	123204	100%	577505	100%	229602	100%	63198	100%	120510	100%
5		(10%)		(46%)		(18%)		(5%)		(10%)	Pct.
Sn.	Appliances	6		7		8		9		10	
	Income Group	Entertainment		Other		Total Elect. Cons.		Household		Population	
		kWh	Pct.	kWh	Pct.	kWh	Pct.	kWh	Pct.	kWh	Pct.
1	≤ 4 Lakh	39704	50%	28083	52%	568919	46%	3818.25	22%	692.12	24%
2	4 L-8 L	19826	25%	13116	24%	283977	23%	4655.36	27%	771.68	27%
3	8 Lakh+	19127	24%	12455	23%	393434	32%	8742.98	51%	1405.12	49%
4	Total	78657	100%	53654	100%	1246330	100%	17216.59	100%	2868.91	100%
5		(6%)		(4%)		(100%)		3818.25	22%	692.12	24%
								13.58 Unit/HH/day		2.36Unit/Person/day	

V. REGRESSION ANALYSIS

A multiple regression model (Stepwise Methods) was developed for understanding the impact of total electricity consumption on all variables in the system. In this model total electricity consumption (y) is considered as dependent variable, and the following independent variables, such as Electricity Bill (Rs./year) (x1), Total General Appliances (kWh) (x2), Immersion Rod (kWh) (x3), 2W & 4W Petrol (km) (x4), Wood/Coal (Kg/year) (x5), Total Light Appliances (kWh) (x6), Water pump (nos) (x7), Daylight (nos) (x8), Desert Cooler (nos) (x9), Room Heater (kWh) (x10), Upto 5 (nos) (X11), Female (nos) (X12), Bath (hot water) (X13), Pressure water supply (X14), Professional Graduate (nos) (X15), Store (nos) (X16), Recreation (km) (X17), Domestic Water Supply (X18), Clothes (Rs./year) (X19), Kitchen (nos) (X20), Clothes (Hot water) (X21), 4Wheeler (nos) (X22) and Tenure (nos) (X23) are considered. The model equation is given as per

$$Y = (0.184 \times X1) + (0.035 \times X2) + (0.024 \times X3) + (0.001 \times X4) + (-0.066 \times X5) + (0.054 \times X6) + (28.104 \times X7) + (-15.833 \times X8) + (12.719 \times X9) + (0.037 \times X10) + (-8.542 \times X11) + (9.206 \times X12) + (-27.285 \times X13) + (-20.309 \times X14) + (-38.712 \times X15) + (11.191 \times X16) + (-0.006 \times X17) + (-20.583 \times X18) + (-0.001 \times X19) + (-13.679 \times X20) + (-13.567 \times X21) + (-18.429 \times X22) + (-17.859 \times X23) + 219.444 \quad (1)$$

VI. RESULTS AND DISCUSSION

The model results show that the adjusted R square value is 1.0, which shows that 100% variation in kWh household income explained by these explanatory variables included in the model. It is observed from the ANOVA table that the F (23, 253) = 87889.895 and the p-value is less than 0.001, which shows that the overall model is statistically significant at 1% level. Further, the variables, such as Electricity Bill (Rs./year), Total General Appliances (kWh), Immersion Rod (kWh), 2W & 4W Petrol (km), Wood/Coal (Kg/year), Total Light Appliances (kWh), Water pump (nos), Desert Cooler (nos), Room Heater (kWh), Upto 5 (nos), Female (nos), Bath (hot water), Pressure water supply, Professional Graduate (nos), Recreation (km) and Domestic Water Supply are having the observed p-value was as $p < 0.005$, and whereas Daylight (nos), Store (nos), Clothes (Rs./year), Kitchen (nos), Clothes (hot water), 4Wheeler (nos), Tenure (nos) are having $p < 0.05$ which denotes that these variables are statistically significant in the model. For example, if all the variables except

Electricity Bill (Rs./year) are constant, then the total electricity consumption per household would increase by 0.184 kWh. With a similar assumption, effects of all other variables are held constant, then the total electricity consumption per household would increase as follows: 0.184 kWh per additional amount increase in Electricity Bill (Rs./year), 0.035 kWh per additional appliance increase in Total General Appliances (kWh), 0.024 kWh per additional appliance increase in Immersion Rod (kWh), 0.001 kWh per additional appliance increase in 2W & 4W Petrol (km), 0.054 kWh per additional appliance increase in Total Light Appliances (kWh), 28.104 kWh per additional appliance increase in Water pump (nos), 12.719 kWh per additional appliance increase in Desert Cooler (nos), 0.037 kWh per additional appliance increase in Room Heater (kWh), 9.206 kWh per additional member increase in Female (nos) and 11.191 kWh per additional unit increase in Store (nos).

The Wood/Coal (Kg/year), Daylight (nos), Upto 5 (nos), Bath (hot water), Pressure water supply, Professional Graduate (nos), Recreation (km), Domestic Water Supply, Clothes (Rs./ year), Kitchen (nos), Clothes (hot water), 4Wheeler (nos) and Tenure (nos) exhibited a negative relationship with the total electricity consumption. Therefore, the total electricity consumption would decrease by 0.066 kWh per additional amount decrease in Wood/Coal (Kg/year), 15.833 kWh per additional opinion decrease in Daylight (nos), 8.542 kWh per additional member decrease in up to 5 (nos), 27.285 kWh per additional unit decrease in Bath (hot water), 20.309 kWh per additional unit decrease in Pressure water supply, 38.712 kWh per additional member decrease in Professional Graduate (nos), 0.006 kWh per additional unit distance decrease in Recreation (km), 20.583 kWh per additional unit decrease in Domestic Water Supply, 0.001 kWh per additional amount decrease in Clothes (Rs./year), 13.679 kWh per additional unit room decrease in Kitchen (nos), 13.567 kWh per additional opinion decrease in Clothes (hot water), 18.429 kWh per additional vehicle decrease in 4Wheeler (nos), 17.859 kWh per additional unit decrease in Tenure (nos) under the similar assumption.

VII. Conclusion

In this study, an attempt has been made to analyse the household appliances based on energy consumption in Jodhpur city. Domestic energy consumption is increasing along with the increase in the household's income and living standards. Household's electrical energy consumption pattern has been analyzed thoroughly to identify the control parameters. The identified control parameters are proposed for further energy simulation modal to bridge the gap in energy demand and supply. The author feels that using identified control parameters based on flow models and recommendations if developed for implementation, optimal energy management is anticipated in Jodhpur city.

Appendix A

TABLE IV
ANOVA Model

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000y	1.000	1.000	37.26210

g. Predictors: (Constant), Total HVAC (kWh), Total General Appliances (kWh), Total Cooking appliances (kWh), Total water Heating Source (kWh), Total Light Appliances(kWh), Total Entertainment Appliances (kWh), Total General Other & Other Appliances (kWh)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.81E+09	23	1.22E+08	87889.895	.000[z]
	Residual	3.19E+05	230	1.39E+03		
	Total	2.81E+09	253			

h. Predictors: (Constant), Total HVAC (kWh), Total General Appliances (kWh), Total Cooking appliances (kWh), Total water Heating Source (kWh), Total Light Appliances (kWh), Total Entertainment Appliances (kWh), Total General Other & Other Appliances (kWh)

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	219.444	24.096		9.107	.000
	Electricity Bill (Rs./year)	.184	.000	.991	886.912	0.000
	Total General Appliances (kWh)	.035	.007	.005	5.130	.000
	Immersion Rod (kWh)	.024	.006	.003	4.202	.000
	2W & 4W Petrol (km)	.001	.000	.003	4.243	.000
	Wood /Coal (Kg/ Year)	-.066	.014	-.003	-4.676	.000
	Total Light Appliances(kWh)	.054	.012	.004	4.570	.000
	Water pump (nos)	28.104	7.028	.003	3.999	.000
	Daylight (nos)	-15.833	6.535	-.002	-2.423	.016
	Desert Cooler (nos)	12.719	2.629	.004	4.838	.000
	Room Heater (kWh)	.037	.009	.003	4.075	.000
	Up to 5 (nos)	-8.542	1.779	-.005	-4.801	.000
	Female (nos)	9.206	2.462	.004	3.739	.000

Bath (Hot water)	-27.285	8.904	-.002	-3.064	.002
Pressure water Supply	-20.309	6.121	-.002	-3.318	.001
Professional Graduate (nos)	-38.712	12.143	-.002	-3.188	.002
Store (nos)	11.191	4.668	.002	2.398	.017
Recreation (km)	-.006	.002	-.002	-3.081	.002
Domestic Water Supply	-20.583	5.874	-.003	-3.504	.001
Clothes (Rs./year)	-.001	.000	-.002	-2.585	.010
Kitchen (nos)	-13.679	5.129	-.002	-2.667	.008
Clothes (Hot water)	-13.567	5.519	-.002	-2.458	.015
4Wheeler (nos)	-18.429	8.097	-.002	-2.276	.024
Tenure (nos)	-17.859	8.334	-.002	-2.143	.033

a. Dependent Variable: Total Electricity Consumption (kwh)

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