End-uses of electricity in households of Karnataka state, India

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This paper describes the results of a survey of electricity consumption in a sample consisting of 1,165 households in four districts of Karnataka state in India. The survey revealed the patterns of consumption of electricity in AEH[1] and non-AEH[2] households, the stock of electrical appliances used by the households, the differences in the consumption of electricity in urban and rural areas, the use of other sources of energy for domestic purposes, and the degree of penetration of energy-efficient appliances/devices.

The analysis of electricity consumption of appliances in AEH households showed that the consumption of electricity is mainly due to lighting, air circulation, water-heating and cooking. In non-AEH households, the end-uses accounting for most of the consumption of electricity are lighting, entertainment and air circulation.

The survey also yielded the appliance elasticities and the degree of penetration of energy-efficient devices. As a result policy-makers can take corrective actions by promoting efficiency improvements in certain end-use devices so that increases in the penetration of these devices would not significantly affect the overall electricity requirement for the domestic sector.

1. Introduction

If business-as-usual energy consumption patterns are not viewed as exogenous and "given", but as alterable through interventions, then the question arises regarding the nature of the interventions to influence these patterns. Obviously, the interventions must depend upon the determinants of energy consumption. In the case of residential electricity consumption, what are the main determinants? The conventional thinking is that income is the main determinant. Even if this is the case, it is politically unacceptable to think of income-reduction policies to reduce electricity consumption. Fortunately, a previous study [Reddy, 1990] has shown that income is a weak predictor of residential electricity consumption, explaining only 38 % of electricity consumption. In contrast, it was shown in that study that the appliance stock could explain as much as 93 % of the dependent variable. Appliance stock, therefore, is a much better predictor of electricity consumption than income.

The formulation of plans and programmes for the power sector, especially for the demand for energy and its management, requires an understanding of the appliances that explain electricity consumption. With this objective, a study of household electricity consumption in the state of Karnataka in India was carried out in 1994-95 by the International Energy Initiative (IEI) in collaboration with the Karnataka Electricity Board (KEB) by conducting surveys in the Bangalore, Tumkur, Bijapur and Uttara Kannada districts of Karnataka.

In the year 1994-95, there were 4.898 million domestic electrical connections in Karnataka state. Of these, 963,000 (20 %) were of the AEH or 15-amp limit category corresponding to a 3.5 kVA connected load, and 3.935 million (80 %) were of the non-AEH or 5-amp limit category corresponding to a 1.15 kVA load. In terms of annual electricity consumption, out of a total of 2.322 TWh (or billion units), AEH connections accounted for 1.296 TWh (56 %) and non-AEH connections for 1.026 TWh (44 %). The average monthly consumption per connection works out to about 112 kWh (units) in AEH connections and 22 kWh in non-AEH connections.

Table 1 shows the electricity consumption shares of AEH and non-AEH electricity connections in the four districts surveyed.

There have been a number of previous studies of residential electricity consumption. Wilson [1971] and Anderson [1973] estimated the effect of household characteristics and price of electricity on the household consumption by analysing the cross-sectional data. They concluded that price is the major determinant of electricity

Table 1. Shares in electricity consumption of AEH and non-AEH households in the surveyed districts

District	Number of connections	Non-AEH	AEH
Bangalore	958,430	61 %	39 %
Bijapur	142,804	93 %	7 %
Tumkur	237,529	91 %	9 %
Uttara Kannada	87,740	91 %	9 %

consumption. Houthekar's [1973] study in Great Britain yielded the short-run income and price elasticities, i.e., the effect of income and price on electricity consumption by keeping the stock of appliances constant. Fisher and Kayson [1962], in their analysis of residential electricity consumption in the United States of America, established that residential electricity demand is proportional to the stock of appliances. Parti and Parti [1980] used regression analysis to disaggregate the total household consumption into appliance-wise consumption.

In his doctoral thesis, Reddy [1990] used three different approaches to study the residential electricity demand in the metropolis of Bangalore in Karnataka: the engineering approach, the appliance stock approach and the appliance census approach. He established that the appliance stock and appliance census approaches explained the end-use consumption of electricity much better than the engineering approach. The present study is based on a survey of the appliance stock in selected (sample) households.

Reddy et al. [1991] showed that in the estimation of future energy demand, the shift from one source of energy to another (for example, shift from electric stoves to LPG stoves for cooking) and the use of energy-efficient end-use devices (replacing incandescent bulbs with compact fluorescent lamps or CFLs) to improve energy efficiencies are very important. Hence, the present study also focuses on studying the different sources of energy used for various end-uses in a household and the degree of penetration of energy-efficient devices.

Another study jointly carried out by the Integrated Rural Technology Centre (IRTC) and IEI [IRTC and IEI, 1996], analysing the end-uses of various categories of appliances in the different electricity-consuming sectors showed that in the domestic sector the electricity consumption varies between the urban and rural households as the respective appliance stocks are significantly different. Also, across different slabs of electricity usage (nine slabs were considered on the basis of the quantum of annual consumption of electricity) there exists a growth trend in the appliance stock possessed by these households. The present study has benefited from this particular study in overcoming several shortfalls and difficulties encountered during the pilot study and survey.

2. Objectives of the study

The following objectives guided the present study:

- to disaggregate household electricity consumption by energy service and by end-use device;
- to analyse differentials across consumption slabs, rural/urban regions and AEH/non-AEH connections;
- to conduct an "ABC" analysis of energy services;
- to analyse the composition of household stock of electrical appliances and inter-class differentials;
- to analyse the relative importance (in terms of number of household users) of various sources of energy in meeting household energy service needs; and
- to assess the penetration of energy-efficient electrical appliances/fixtures.

3. Methodology and sample selection

The survey[3] research method adopted for the study used a questionnaire consisting of five sections with open-ended questions. The questionnaire was initially tested by means of a pilot study and then finalised on the basis of the comments, suggestions and responses obtained from the pilot study.

The sample chosen for the survey was stratified and represented four different regions of Karnataka, namely, metropolitan, coastal, northern and southern. The sample consisted of 1,165 households, of which 796 had non-AEH connections and 369 had AEH connections. However, originally it was intended to survey 1,200 (825 non-AEH and 375 AEH) households. These households were selected from four districts of Karnataka – Bangalore (metropolitan region), Tumkur (southern region), Bijapur (northern region) and Uttara Kannada (coastal region). It was also decided to survey both AEH and non-AEH households in the towns but mostly non-AEH households in the rural areas. Depending on the monthly electricity consumption, the households were grouped into six slabs – Slab #1 corresponded to a monthly consumption of 0-100 kWh; Slab #2, 100-200 kWh; Slab #3, 200-300 kWh; Slab #4, 300-400 kWh; Slab #5, 400-500 kWh; Slab #6, 500 kWh and above. The number of houses to be covered in each of the slabs was decided on the basis of the number of users in each slab as identified by the KEB. The purpose of grouping the sample into different slabs was to analyse the differences in the pattern of usage of electricity across the slabs.

For the purpose of analysis, the statistical techniques of multiple regression analysis, step-wise regression analysis, analysis of variance (ANOVA), ratios and proportions, descriptive statistics and t and F tests were used.

In this study, three different approaches are used to study the electricity consumption of end-use devices in a household: the engineering approach, the appliance stock approach and the appliance census approach.

The engineering approach is based on sample surveys of variables such as number of appliances, rated power of these appliances and number of hours of usage of these appliances. An engineering estimate of electricity consumption of the end-uses will mainly depend on the number of hours of usage of each appliance possessed by the households. As these figures are obtained from users, they may not be correct estimates (as far as statistical significance is concerned) since they depend on the reliability of the user in estimating the usage hours.

Table 2. Electricity consumption data for the districts studied, as reported by KEB and as determined by the study

	As reported by KEB[1]		From the sample[1]	
	AEH	**Non-AEH**	**AEH**	**Non-AEH**
Avge. elec. consumption for state (kWh/yr)	1344	264	2094	324
Std. deviation (sample)	-	-	1098	261
No. of consumers	962534	3934677	369	796
No. of consumers in Bangalore district	515194 (53.5)[2]	742512 (18.8)	156	51
No. of consumers in other districts[3]	52766 (5.5)	527464 (13.4)	213	745
Bangalore district's load (kW)	1258306 (51.8)	234690 (22.2)	827 (58.4)	34.0 (5.2)
Bangalore district's consumption (kWh/yr)			3062	440.9
Other districts'[3] consumption (kWh/yr)			1238	289.8
Other districts'[3] load (kW)	117669 (4.8)	122036 (11.5)	587.5 (41.6)	625.3 (94.8)
Total load for the state (kW)	2427435	1055689	1414.5	659.4

Source: KEB, 1995

Notes

1. The data pertains to the year 1994-95.
2. The figures in parentheses are the corresponding percentages in the total.
3. The other districts are Bijapur, Tumkur and Uttara Kannada.

In the appliance stock approach the total electricity consumed by a household will depend on the total load (wattage of the appliances possessed by the household) accounted by a household. This could also be a poor predictor as the coincidence factor for usage of these appliances is not available.

The appliance census approach uses regression analysis to determine the contribution of various categories of appliances to the total electricity consumption. This could be a more reliable approach as the regression coefficients indicate the marginal change in electricity consumption per unit change in the number of appliances of that particular category. And, if the change is linear, the regression coefficient is also the average electrical energy consumed through that category of appliances.

4. Results

4.1. AEH and non-AEH connections

In all, the data that was used for the analysis comprised 369 (31.67 %) AEH and 796 (68.33 %) non-AEH households. The average family sizes in AEH and non-AEH households are almost the same, 5.60 and 5.61). The average number of rooms in AEH households is 1.4 times that of non-AEH households (4.75 rooms/AEH household and 3.46 rooms/non-AEH household). The average electricity consumption in AEH households is 2,094 kWh/year with a standard deviation of 1,098 kWh/year which is more than 6 times that of non-AEH households, with an average consumption of 324 kWh/year with a standard deviation of 261 kWh/year. The estimate of average electricity consumption per household in both the AEH and non-AEH samples is *more* than the actual values reported in the annual reports of KEB. This discrepancy (even though it is well within the mean plus/minus standard deviation) could be attributed to the fact that more AEH households (156 out of 369) and less non-AEH households (51 out of 796) were considered from Bangalore district (metropolitan area) where the connected load is about 51 % of the state's total connected load for the AEH households and 22 % of the total connected load for the non-AEH households as reported by KEB. In contrast, the other three districts from which the sample was chosen together account for only 4.8 % of the AEH load and 11.5 % of the non-AEH load of the state (Table 2). Secondly, the average electricity consumption in AEH households in Bangalore district is 3,062 kWh/year whereas for the other three districts the average electricity consumption in AEH households is 1,237 kWh/year which is much closer to the state average of 1,344 kWh/year for all districts as reported by KEB.

4.2. Appliance stock

There is a difference in the number of appliances of various types owned by AEH and non-AEH households in each category of usage, such as water-heating, lighting, and cooking. Appliances such as immersion water-heaters (IWHs, commonly known as "immersion rods", which heat water in a container by being immersed in it), storage water-heaters (StWHs, commonly known as "geysers"), hot plates, washing machines, refrigerators, kettles, vacuum cleaners, toasters and pumps (to lift water from sumps to overhead tanks) are special features of AEH households. In contrast, very few of the non-AEH households have hot plates, StWHs, pumps and refrigerators. Figure 1 gives the difference in the proportion of households using appliances such as televisions (TVs), 40-W fluorescent tubes (FT40s), 60-watt incandescent lamp (IL60s), 40-W incandescent lamps (IL40s), mixers and electric irons, which are common to both AEH and non-AEH categories. In the AEH category, 80.2 % of the households have televisions, whereas in the non-AEH

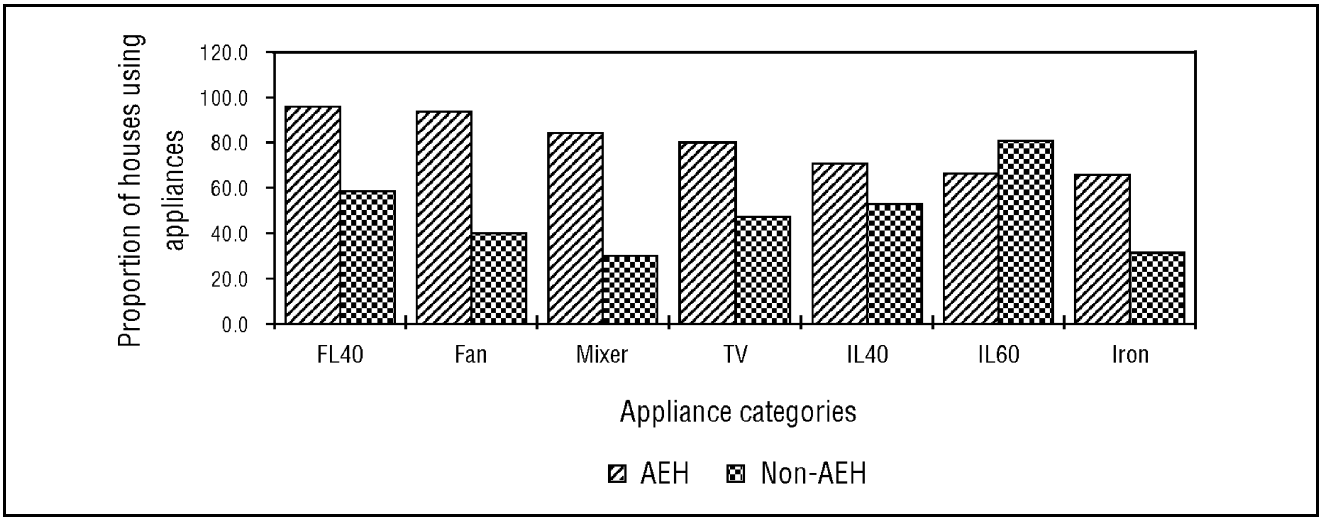

Figure 1. Proportion of households using appliances common to AEH and non-AEH categories

households, the penetration of TVs is only 47.1 %. Ceiling-fans are more prominent among the AEH households (93.4 %) than in non-AEH households (40 %). A larger proportion of households in the non-AEH category use IL60s but larger proportions of AEH homes use FT40s and IL40s. The proportion of households using mixers in the AEH category is almost double that in the non-AEH category.

The average numbers of appliances found in both AEH and non-AEH households in the sample are given in Table 3. The results indicate that even though incandescent lamps are a common feature in both AEH and non-AEH households, the number of bulbs per 100 households varies from 54 in the AEH to 37 in the non-AEH. In the case of fluorescent tubes, the average number per 100 households is 43 for AEH whereas it is only 10 for non-AEH. For most of the appliances, the standard deviation is quite large, which indicates that much variation exists among the households in the usage of different appliance categories in both AEH and non-AEH households.

4.3. Engineering approach

From the survey data on appliance stock, wattage and hours of usage, the engineering estimates of the household electricity consumption can be obtained (Appendix A). These estimates were calculated for each of the appliance categories in both AEH and non-AEH households and the results are tabulated in Tables 4 and 5. Lamps (incandescent and fluorescent), fans, refrigerators, StWHs, IWHs and hot plates are estimated to consume 79 % of the average electricity consumption per AEH household, whereas lamps, fans, televisions and electric irons are estimated to consume 83.38 % of the average electricity consumption per household in the non-AEH category. Lighting in non-AEH households accounts for a high percentage (76.42 %) of the average electricity consumption per household, while in AEH households its share is only 39.28 %.

The engineering estimates of the total household consumption were compared by regression with the actual values (obtained through meter readings recorded by KEB). The resulting R^2 is 0.37 for AEH and 0.04 for non-AEH, and the standard errors of estimates are 1,361 and 196 kWh, which are more than 60 per cent of their average consumption (2,094 and 324 kWh respectively). The large standard errors indicate that there are huge differences between the estimated and actual values. Hence, the engineering approach has serious limitations in estimating the actual energy consumption of appliances primarily because it depends largely upon recall of the hours of usage.

4.4. Appliance stock approach

In the appliance stock approach (Appendix A), the yearly electricity consumption was regressed on the household load. The result in the AEH category was $E_i = 166.7 + 480.5\ L_i$ (25.6) and $R^2 = 0.48$ and the result in the non-AEH category was $184.5 + 167.6\ L_i$ (11.9) and $R^2 = 0.19$. From this analysis, one can conclude that a unit (kW) increase in load results in an increase of 480 kWh per year in electricity consumption in the AEH category and 160 kWh per year in the non-AEH category.

The actual increase would be different if the coincidence factor of using the appliances at the same time is taken into account. Also, the household load due to appliance stock explains only 48.9 % of the variation in the AEH category and only 19 % of the variation in the non-AEH category. Even though these are low, they are much better when compared with the corresponding figures for the engineering approach.

4.5. Appliance census approach

Using the appliance census approach (Appendix A), regression analysis was carried out on the samples of AEH and non-AEH households separately. The number of appliances considered in both categories of sample households was large (32 appliance categories); hence the linear multiple regression resulted in some negative and statistically insignificant coefficients that were difficult to interpret. A stepwise multiple linear regression analysis was therefore performed. In the stepwise regression analysis for the AEH sample, most of the appliance categories such as kettles, toasters, battery-chargers, vacuum cleaners, inverters, washing machines, radios, VCRs, mono tape recorders and step-up transformers were eliminated because

Table 3. Appliance stock in the sample

Sl. no.	Appliance	non-AEH		AEH	
		Average	Std. dev.	Average	Std. dev.
1.	Table lamp	0.17	0.39	0.11	0.31
2.	Table fan	0.21	0.41	0.17	0.38
3.	Mixer	0.30	0.46	0.84	0.36
4.	Refrigerator	0.02	0.13	0.58	0.49
5.	Air cooler			0.04	0.18
6.	Air conditioner			0.01	0.10
7.	Toaster			0.03	0.16
8.	Hot plate	0.01	0.11	0.27	0.44
9.	Kettle			0.04	0.19
10.	Electric iron	0.31	0.46	0.66	0.48
11.	StWH			0.31	0.47
12.	IWH	0.01	0.09	0.36	0.48
13.	Vacuum cleaner			0.12	0.32
14.	Television	0.47	0.5	0.8	0.40
15.	VCR	0.01	0.09	0.19	0.40
16.	Radio	0.42	0.49	0.24	0.43
17.	Mono recorder	0.24	0.43	0.22	0.42
18.	Stereo recorder	0.07	0.26	0.3	0.46
19.	Electric heater			0.06	0.24
20.	Battery charger			0.01	0.12
21.	Inverter			0.00	0.00
22.	Washing machine			0.21	0.40
23.	Step-up transformer			0.04	0.19
24.	Water pump	0.01	0.11	0.43	0.49
25.	FL20[1]	0.01	0.18	0.02	0.15
26.	FL40[1]	1	1.25	4.032	0.95
27.	IL15	0.25	0.67	0.22	0.73
28.	IL40	1.13	1.51	2.26	0.64
29.	IL60	2.12	1.57	2.61	0.76
30.	IL100	0.02	0.17	0.08	0.48
31.	IL25	0.18	0.54	0.23	0.71
32.	Fan	0.5	0.69	2.66	0.85

Note

1. The ballast consumption is not included in this analysis.

these appliances contribute only about 2 % of the total electricity consumption (see Table 3). The result of the stepwise regression analysis on the AEH households is given in Table 6. The result indicates an R^2 value of 0.62, meaning that 62 % of the variation in electricity consumption among the AEH households is explained by the 12 categories of appliance included in the model. The standard error of estimate (1,070 kWh) is on the high side when compared with the mean (2,094 kWh). The reasons for the somewhat low R^2 value and the high error coefficient could be attributed to (1) the fact that a household may not put to much use the appliances that it possesses[4] and (2) the usage of some of the appliances is not taken into account because step-wise regression removes less significant appliances.

Similarly, a step-wise regression analysis was performed on the non-AEH sample households. The result (Table 7) indicates an R^2 value of 0.31, explaining 31 % of the variation in the electricity consumption by the 9 categories of appliances in the non-AEH households. This is quite low perhaps because the 60-W incandescent bulb which accounts for 24.60 % of the total electricity consumption does not have a sufficiently high correlation to appear in the regression model. The standard error (118.59 kWh) is relatively lower than in AEH households when compared with the mean (324 kWh).

The results indicate that television sets, ceiling-fans, and mixers consuming 53.77, 46.48, and 39.28 kWh per year are the highest electricity-consuming appliances in non-AEH households, whereas in AEH households, hot plates and water-heaters (StWHs and IWHs) consume the most electricity with 1,036.15 and 960.53 kWh per year.

The implied usage hours thus obtained from the regression analysis make much better sense than the user-reported usage hours. For example, a hot-plate user would use it for all the household cooking (if the user does not have cooking gas as a stand-by), which turns out to be at least a couple of hours a day, but only 1 hour of usage has been reported by the households.

4.6. End-use analysis in the residential sector

By knowing the consumption of different appliances, the electricity consumption for different end-uses in the households can be estimated. Using the appliance-wise consumption figures, electrical energy used for different end-uses can be calculated using the formula

$$E_{im} = \sum_{j} X_{ijm} \times b_{ijm}$$

where E_{im} is the consumption of electricity for the mth end-use and X_{ijm} is the number of appliances of type j in the ith household.

Using the above equation, the electrical energy for the different end-uses was obtained for both AEH and non-AEH households. (The consumption of different appliances obtained from the results of the appliance census approach is used.) The result shows that (see Figures 2 and 3 for AEH and non-AEH categories respectively) in the AEH households, lighting devices (27.77 %) consume the most electricity and next follow appliances used for air circulation (23.3 %). Electricity consumed by appliances used for water-heating (18.19 %) and cooking (14.11 %) follow them. In the non-AEH households, lighting devices (39.42 %) consume the most electricity, followed by appliances used for entertainment (23.7 %) and then appliances used for air circulation (20.75 %).

Assuming that the sample represents the whole of Karnataka, that is, the appliance stock in the sample is the same as that of the state, the end-use estimates for residential electricity consumption in Karnataka were obtained. The result (Figure 4) shows that in the residential sector (i.e., both AEH and non-AEH households), lighting

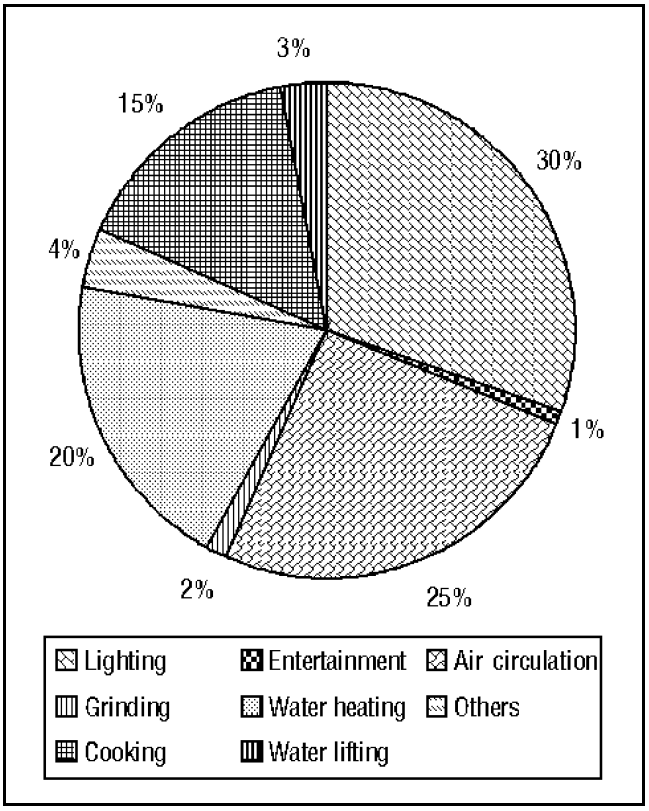

Figure 2. End-use analysis of electricity use in AEH households

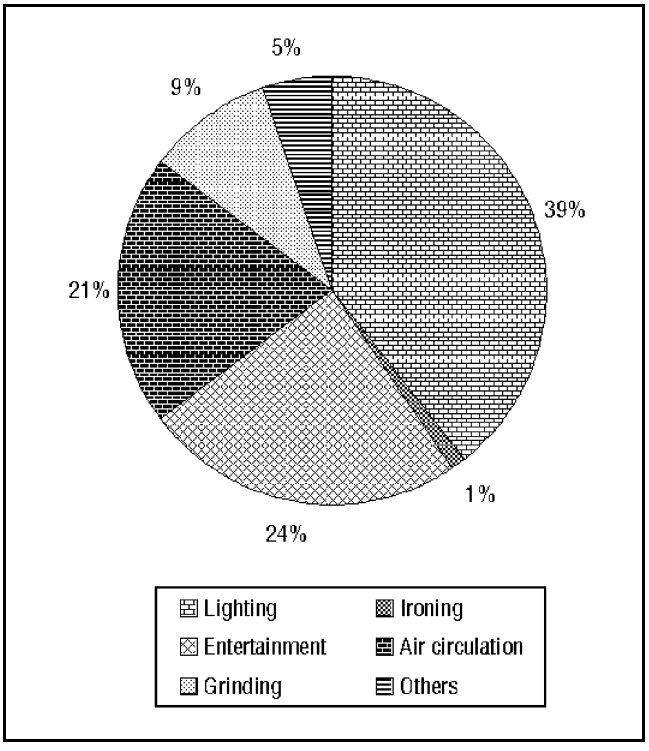

Figure 3. End-use analysis of electricity use in non-AEH households

is the major end-use, accounting for 32.28 % of the total consumption, followed by air circulation with 22.31 %. Water-heating, entertainment and cooking account for 11.09 %, 9.68 % and 8.69 % of the total electricity consumption respectively. Refrigeration, grinding, water-lifting, ironing and other uses account for the remainder.

Electricity consumption in the residential sector consists of heating and non-heating uses. Heating uses mainly include cooking, water-heating and ironing, while non-heating uses are lighting, refrigeration, water-lifting, air circulation, etc. In the total consumption of electricity, heating and non-heating uses account for 21.26 and 78.74 % respectively.

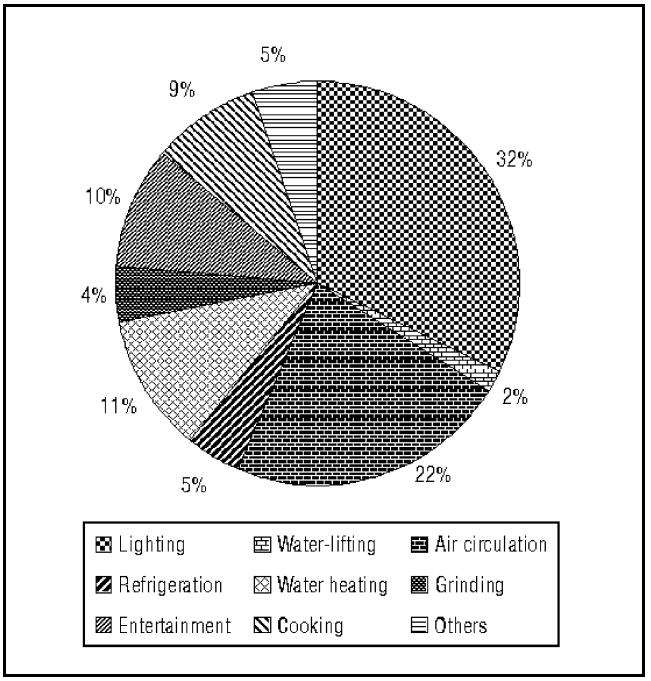

Figure 4. End-use analysis of electricity in the residential sector

4.7. Appliance elasticities

X_{ij} has been defined as the number of appliances of jth category in the ith household, from which it follows that $Y_j = \Sigma_i X_{ij}$ is the number of appliances of the jth category in all the N households. Further, $Y_j/N = X_j$ is the average number of appliances of the jth category per household. X_j can also be described as the penetration of the jth category of appliances.

If the penetration X_j of appliances of the jth category is increased by unity, i.e., one more appliance of this category is added to the appliance stock, then the percentage change in the penetration is $(100\times1/X_j)$. In response to this change, the yearly household energy consumption is increased by b_j and the percentage increase in the average yearly household consumption is $(100\times b_j/E)$ where E is the average yearly electricity consumption of households. Conventionally, elasticity is defined as the ratio of these two percentage changes. Thus, the appliance elasticity of household electricity consumption is:

$$e = \frac{\text{Percentage change in electricity consumption}}{\text{Percentage change in appliance penetration}}$$

$$= [(100\times b_j)/E]/[(100\times1)/X_j)] = [(b_j\times X_j)/E]$$

The effects of increases in appliance penetration on future electricity demand can be estimated by using these elasticities. The elasticities thus calculated for various appliances in both AEH and non-AEH households are given in Table 8.

Further, using the elasticities, an estimate of future electricity demand per increase in appliance penetration for

Table 4. Household consumption of electricity (AEH)

Appliance category	Wattage	Average appliance no. per hh	Usage hr/day	Usage hr/yr	Consumption kWh/yr		% of total
					per app	per hh	
Table lamp	40	0.1	2.54	927	37.08	3.71	0.15
Table fan	60	0.17	4.76	1737	104.24	17.72	0.69
Mixer	450	0.85	0.47	172	77.20	65.62	2.57
Refrigerator	100	0.6	22.33	8150	815.05	489.03	19.17
Air cooler	170	0.03	4.8	1752	297.84	8.94	0.35
Air conditioner	1500	0.01	0.81	296	443.48	4.43	0.17
Toaster	800	0.03	1.1	402	321.20	9.64	0.38
Hot plate	1000	0.28	1.37	500	500.05	140.01	5.49
Kettle	1500	0.03	1.1	402	602.25	18.07	0.71
Electric iron	750	0.67	0.48	175	131.40	88.04	3.45
StWH	3000	0.29	1.18	431	1292.10	374.71	14.69
IWH	1000	0.36	1.75	639	638.75	229.95	9.01
Vacuum cleaner	750	0.12	0.7	255	191.62	23.00	0.90
Television	100	0.81	3.93	1434	143.45	116.19	4.55
VCR	40	0.2	2.14	781	31.24	6.25	0.24
Radio	15	0.23	2.51	916	13.74	3.16	0.12
Mono recorder	20	0.24	1.82	664	13.29	3.19	0.12
Stereo recorder	50	0.31	1.74	635	31.76	9.84	0.39
Electric heater	1000	0.06	1.72	628	627.80	37.67	1.48
Battery charger	15	0.01	3.25	1186	17.79	0.18	0.01
Washing machine	325	0.21	0.71	259	84.22	17.69	0.69
Step-up transformer	400	0.04	0.89	325	129.94	5.20	0.20
Water pump	750	0.43	0.68	248	186.15	80.04	3.14
FL20	20	0.02	1.3	475	9.49	0.19	0.01
FL40	40	4.09	2.63	960	38.40	157.05	6.16
IL15	15	0.22	2.32	847	12.70	2.79	0.11
IL40	40	2.27	1.56	569	22.78	51.70	2.03
IL60	60	2.64	2.36	861	51.68	136.45	5.35
IL100	100	0.08	2.72	993	99.28	7.94	0.31
IL25	25	0.24	1.27	464	11.59	2.78	0.11
Fan	100	2.71	4.45	1624	162.43	440.17	17.25
Total						2551.34	100.00

Karnataka has been calculated and listed in Tables 9 and 10 for AEH and non-AEH households respectively. The electricity demand is calculated by using the average consumption and number of households with AEH and non-AEH connections.

The elasticities of IL60s and IL100s in the AEH category are quite different as the numbers of bulbs used in these two categories of appliances differ greatly. (From Table 3 it is clear that on an average an AEH household has 3 IL60s, compared with 1 IL100.)

The elasticities of fans in AEH and non-AEH categories are different and could be attributed to the following: the average number of rooms in an AEH house is 5 compared with 3 in a non-AEH household. Also, the electricity consumed by fans by an AEH household is 180.94 kWh/year, compared with 107.6 kWh/year by a non-AEH household.

4.8. Rural and urban households

The sample consists of 46 rural and 323 urban households in the AEH category and 351 rural and 445 urban households in the non-AEH category. The average consumption of electricity per household in rural areas is 940 kWh and 240 kWh per year for the AEH and non-AEH households respectively whereas in urban areas it is 2160 kWh and 390 kWh per year for AEH and non-AEH households

Table 5. Household consumption of electricity (non-AEH)

Appliance category	Wattage	Average appliance no. per hh	Usage hr/day	Usage hr/yr	Consumption kWh/yr		% of total
					per app	per hh	
Table lamp	40	0.17	2.91	1062	42.49	7.22	1.04
Table fan	60	0.21	5.78	2110	126.58	26.58	3.84
Mixer	450	0.3	0.52	190	85.41	25.62	3.70
Refrigerator	100	0.02	24	8760	876.00	17.52	2.53
Hot plate	1000	0.01	1.7	621	620.50	6.21	0.90
Electric iron	750	0.31	0.51	186	139.61	43.28	6.25
IWH	1000	0.01	3.11	1135	1135.15	11.35	1.64
Television	100	0.47	3.67	1340	133.96	62.96	9.09
VCR	40	0.01	2.31	843	33.73	0.34	0.05
Radio	15	0.42	2.22	810	12.15	5.10	0.74
Mono recorder	20	0.24	2.25	821	16.43	3.94	0.57
Water pump	750	0.01	1.06	1500	1125.11	11.25	1.62
FL20	20	0.01	4.11	1190	23.80	0.24	0.03
FL40	40	1	3.26	2763	110.52	110.52	15.96
IL15	15	0.25	7.57	920	13.80	3.45	0.50
IL40	40	1.13	2.52	1205	48.18	54.44	7.86
IL60	60	2.12	3.3	1340	80.37	170.39	24.60
IL100	100	0.02	3.67	398	39.79	0.80	0.11
IL25	25	0.18	1.09	2413	60.32	10.86	1.57
Fan	100	0.5	6.61	2413	241.27	120.63	17.41
Total						692.71	100.00

respectively. Thus, the difference in consumption of electricity between AEH rural and urban households is quite large.

4.9. District-wise analysis

The consumption of electricity by a household can also depend on the location and the socio-economic factors of the household. The average consumption of electricity for each of the slabs of usage in the AEH and non-AEH households in Bangalore, Tumkur, Bijapur and Uttara Kannada districts was estimated. From the estimates, it is observed that the average consumption for all the slabs in metropolitan Bangalore is much higher than the values for the other three districts, which do not show significant differences among them.

Using the ANOVA test, the differences in the average consumption of electricity across the slabs and across the districts were studied. The results of the ANOVA test indicate that there are differences in the average electricity consumed by the households in the different districts and across different slabs of usage. This justifies the sample selection and its purpose.

4.10. Appliance stock in the districts

The district-wise analysis also revealed that there are differences in the average stock of appliances possessed by a household in each of the four districts.

Using the engineering approach, the household consumption of electricity for both AEH and non-AEH households were estimated for the four districts. (The engineering approach has been used here even though it may not yield an accurate estimate as explained earlier as the district-wise sample size was too small to use the appliance census approach.) Figures 5 and 6 show the differences in the proportion of consumption of electricity by various end-uses in the four districts studied.

The results indicate that water-heating is prominent in the households of Bangalore, with 29.39 % of the total electricity consumption accounting for it. The lowest consumption of water-heating is in the households of Uttara Kannada district, probably because this coastal region has higher ambient temperatures. The share of air circulation in total electricity consumption for the households in Uttara Kannada and Bijapur districts is 36.91 % and 28.61 % respectively. Households in Bangalore district use 12.2 % of their total electricity consumption for lighting, which is very low compared with the other districts. In the non-AEH category, lighting devices use about 65 % of the total consumption of electricity in all the districts. The non-AEH households of Uttara Kannada district use

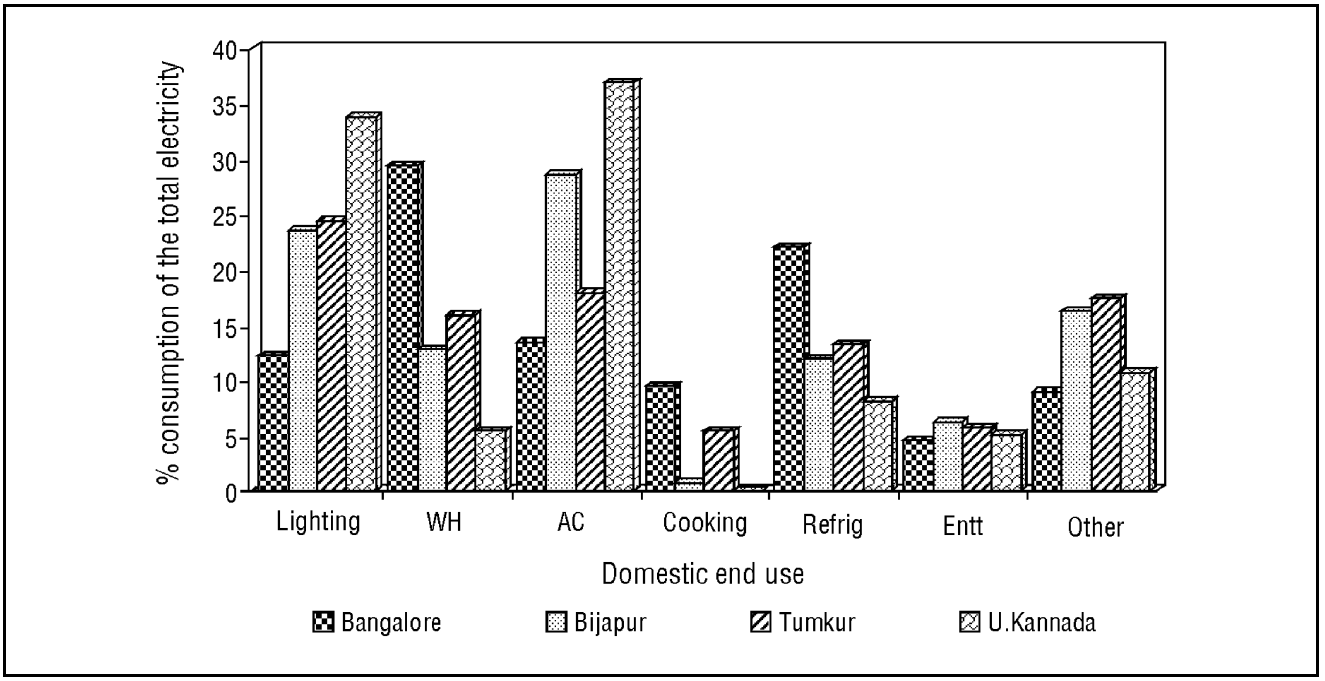

Figure 5. End-use analysis of electricity consumption district-wise (AEH category)

Key: WH = water heating; AC = airconditioning; Refrig = refrigeration; Entt = entertainment

Table 6. Appliance-wise consumption (AEH)

Sl. no.	Appliance	Consumption/ appliance (kWh/yr)	Standard deviation	T	Sig T
1.	Fan	180.94	55.40	3.26	.001
2.	Radio/tape rec.	22.23	93.88	.23	.812
3.	IL100	102.44	119.23	.85	.390
4.	IWH	516.77	142.30	3.63	.000
5.	Mixer/grinder	36.24	174.60	.20	.835
6.	Pump	133.77	124.45	1.07	.283
7.	IL40	39.32	23.63	1.66	.097
8.	Hot plate	1061.81	148.60	7.14	.000
9.	IL60	86.90	17.80	4.88	.000
10.	Refrigerator	265.94	144.25	1.84	.066
11.	StWH	667.89	166.10	4.02	.000
12.	FL40	63.34	26.72	2.37	.018
(Constant)		77.62			
Multiple R		.79031			
R square		.62460			
Adjusted R square		.61127			
Standard error		1070.89579			

Analysis of variance

	DF	Sum of squares	Mean square
Regression	12	644932093.01549	53744341.08462
Residual	356	387624412.49449	1146817.78845
F = 46.86389		Signif. F = .0000	

Table 7. Appliance-wise consumption (non-AEH)

Sl. no.	Appliance	Consumption/ appliance (kWh/yr)	Standard deviation	T	Sig T
1.	Fan	107.69	13.44	8.00	.000
2.	Table fan	64.13	19.45	3.29	.001
3.	IL100	93.41	45.10	2.07	.038
4.	Radio	66.81	16.31	4.09	.000
5.	Table lamp	26.88	21.22	1.26	.205
6.	Mono tape rec.	36.93	18.68	1.97	.048
7.	Electric iron	13.04	18.67	0.69	.485
8.	FL40	18.41	7.22	2.55	.011
9.	Mixer/grinder	95.87	19.55	4.90	.000
10.	Television	86.68	18.52	4.68	.000
(Constant)		120.922521			
Multiple R		.56042			
R square		.31407			
Adjusted R square		.30533			
Standard error		129.37037			

Analysis of variance

	DF	Sum of squares	Mean square
Regression	10	16983056.04918	1698305.60492
Residual	785	37091155.37796	47249.87946
F = 35.94307		Signif. F = .0000	

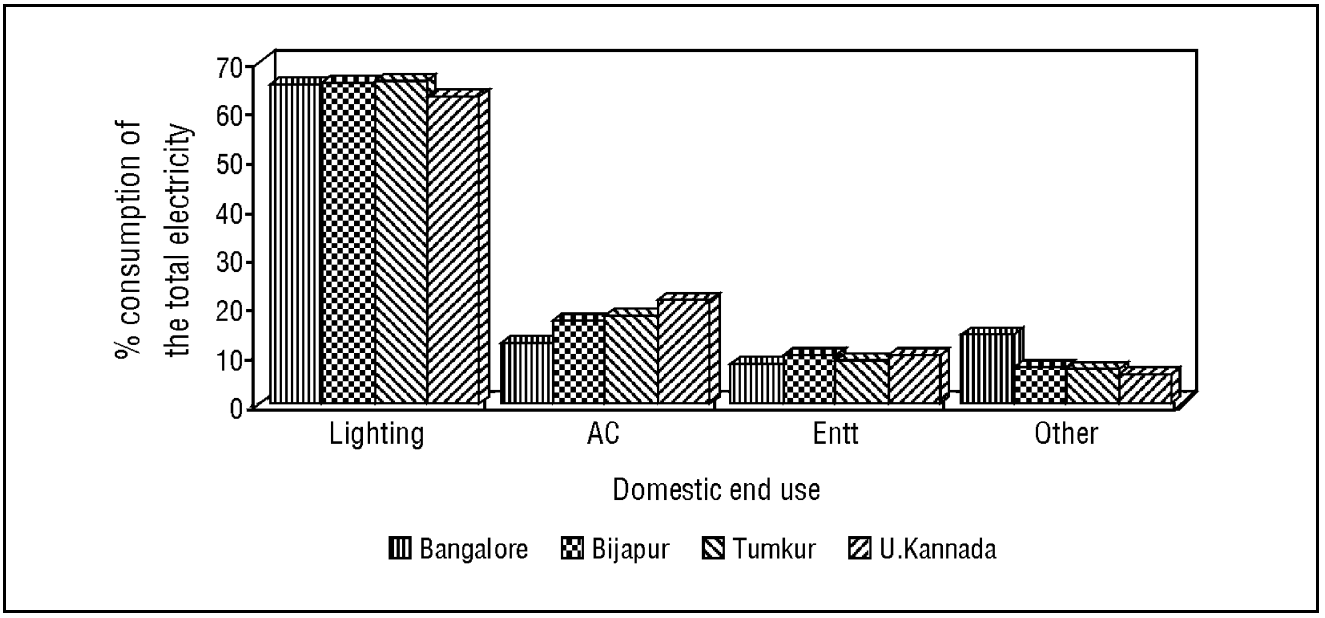

Figure 6. End-use analysis of electricity consumption district-wise (non-AEH category). Key: AC = airconditioning; Entt = entertainment

Table 8. Appliance elasticities

Sl. no.	Appliance	Appliance-wise consumption (kWh/yr)		Appliance penetration		Elasticity	
		Non-AEH	AEH	Non-AEH	AEH	Non-AEH	AEH
1.	Table fan	64.13		0.21		0.04	
2.	Refrigerator	265.9		0.6		0.08	
3.	Hot plate		1061.8		0.28		0.14
4.	Electric iron	13.04		0.31		0.01	
5.	StWH		667.89		0.29		0.09
6.	IWH		516.77		0.36		0.09
7.	Television	86.68		0.47		0.13	
8.	Radio	66.81		0.42		0.09	
9.	Mono recorder	36.93	22.16	0.24	0.78	0.03	0.01
10.	Stereo recorder						
11.	Water pump		133.77		0.43		0.03
12.	FL40	18.42	63.34	1	4.09	0.06	0.12
13.	IL40	25.72	39.32	1.13	2.27	0.09	0.04
14.	IL60	72.38	86.9	2.12	2.64	0.47	0.11
15.	IL100	93.42	102.44	0.02	0.08	0.01	0.004
16.	Table lamp	26.88		0.17		0.01	
17.	Fan	107.6	180.94	0.5	2.71	0.17	1.51
18.	Mixer/grinder	95.87	36.24	0.3	0.85	0.09	0.01

Sample calculation:

$$\text{Appliance elasticity} = \frac{\text{Consumption of electricity by an appliance} \times \text{average no. of appliances in a household}}{\text{Average electricity consumption per household}}$$

(for sl. no. 1) = $64.13 \times 0.21/324 = 0.041$

Table 9. Effect of unit percentage appliance penetration on AEH electricity consumption

Appliance	Consumption/ appliance (kWh/yr)	Elasticity	Increase in consumption	
			per hh kWh/yr	Karnataka GWh/yr
1. Refrigerator	265.9	0.076	1.60	1.54
2. Hot plate	1061.8	0.142	2.97	2.86
3. StWH	667.89	0.092	1.94	1.87
4. IWH	516.77	0.089	1.86	1.79
5. Radio	22.16	0.008	0.17	0.17
6. Mono recorder				
7. Stereo recorder				
8. Water pump	133.77	0.027	0.58	0.55
9. FL40	63.34	0.124	2.59	2.49
10. IL40	39.32	0.043	0.89	0.86
11. IL60	86.9	0.110	2.29	2.21
12. IL100	102.44	0.004	0.08	0.08
13. Fan	180.94	1.513	31.69	30.52
14. Mixer/grinder	36.24	0.015	0.31	0.30
Total				45.24

Sample calculation:

Increase in consumption per household = elasticity × average consumption of electricity in a household

(for sl. no. 1) = 0.076 % × 2094

= 1.60

Increase in consumption for Karnataka = increase in consumption per household × no. of connections

= $1.60 \times 0.963 \times 10^6$

= 1.54 GWh

Table 10. Effect of unit percentage appliance penetration on non-AEH electricity consumption

Appliance	Consump./ appliance (kWh/yr)	Elasticity	Increase in consumption	
			per hh kWh/yr	Karnataka GWh/yr
1. Table fan	64.13	0.042	0.13	0.53
2. Electric iron	13.04	0.012	0.04	0.16
3. Television	86.68	0.126	0.41	1.60
4. Radio	66.81	0.087	0.28	1.10
5. Mono recorder	36.93	0.027	0.09	0.35
6. FL40	18.42	0.057	0.18	0.72
7. IL40	25.72	0.090	0.29	1.14
8. IL60	72.38	0.474	1.53	6.04
9. IL100	93.42	0.006	0.02	0.07
10. Table lamp	26.88	0.014	0.05	0.18
11. Fan	107.6	0.166	0.54	2.12
12. Mixer/grinder	95.87	0.089	0.29	1.13
Total				15.14

Sample calculation:

Increase in consumption per household = elasticity × average consumption of electricity in a household

(for sl. no. 1) = 0.042 % × 324

= 0.136

Increase in consumption for Karnataka = increase in consumption per household × no. of connections

= $1.60 \times 3.935 \times 10^6$

= 0.53 GWh

about 21 % of their total electricity consumption for air circulation, which is higher than in the other districts.

In order to understand the change in electricity consumption over a period of time by the households in the Bangalore metropolitan area the results obtained by Reddy [1990] were compared with this study. The following are the major changes.

1. The average electricity consumed by an AEH household in 1990 was 215 kWh/month (standard deviation of 86.97) whereas in 1995 it was 255 kWh/month (standard deviation of 91.5).
2. The significant changes in appliance stock owned by the households from 1990 to 1995 are televisions (70 % to 92 %), washing machines (0 to 24 %), water pumps (13 % to 49 %), hot plates (75 % to 56 %), vacuum cleaners (0 to 21 %) and fans (2 fans per household to 4 fans per household).
3. The number of households using an electric stove (hot plate) for cooking has come down by 20 % due to the increase in the usage of LPG for cooking. Also, 90 % of the households possessing hot plates reported using them as a stand-by for LPG.

4.11. Other sources of energy for domestic purposes

The survey also focused on the usage of other sources of energy for different end-uses. The other sources of energy include liquefied petroleum gas (LPG), kerosene, fuelwood and biogas used for the purposes of cooking, water-heating and lighting.

About 88.8 % of the AEH households and 27.6 % of the non-AEH households use LPG regularly for cooking and/or for water-heating and/or for lighting (Table 11). All the households (both AEH and non-AEH) mention the usage of LPG for cooking. Only 18 % of AEH households and 54 % of the non-AEH households use LPG for heating water.

Kerosene (75.1 %), firewood (72.9 %) and to a certain extent crop wastes (44 %) are used extensively for cooking and water-heating in the non-AEH households. Even though AEH households could use electricity and/or LPG for cooking and water-heating, a surprisingly high percentage use kerosene and firewood for cooking (31 % and 16 %) and water-heating (19 % and 26 %). Hence, the

Table 11. Details of usage of other sources of energy in AEH and non-AEH households

Sl. no.	Source of energy	Usage by number of hh		Average usage per hh/month		No. of hh use for cooking		No. of hh use for water heating		No. of hh use for lighting	
		AEH	N-AEH	AEH	N-AEH	AEH	N-AEH	AEH	N-AEH	AEH	N-AEH
1.	LPG (kg)	328	220	12	3.7	328	220	62	119	5	11
		(88.8 %)	(27.6 %)			(100 %)	(100 %)	(18.9 %)	(54 %)	(1.52 %)	(5 %)
2.	Kerosene (l)	152	598	2.93	6.26	116	519	71	341	50	214
		(41.2 %)	(75.1 %)			(76 %)	(86.7 %)	(46.7 %)	(57 %)	(32.9 %)	(35.8 %)
3.	Firewood (kg)	120	580	88	130	59	459	96	513		
		(32.5 %)	(72.9 %)			(49.2 %)	(79.1 %)	(80 %)	(88.4 %)		
4.	Crop waste (kg)	21	350	4.04	24.96	10	276	20	273		
		(5.7 %)	(44 %)			(47.6 %)	(78.8 %)	(95.2 %)	(78 %)		
5.	Biogas (m^3)	6	24			6	24	5	20		
		(1.6 %)	(3.0 %)			(1.6 %)	(3.0 %)	(1.3 %)	(2.5 %)		

Table 12. Details of usage of other sources of energy in rural and urban dwellings

Sl. no.	Source of energy	Usage by number of hh		Average usage per hh/month		No. of hh use for cooking		No. of hh use for water heating		No. of hh use for lighting	
		Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
1.	LPG (kg)	69	479	2	8.5	69	479	12	169	1	18
		(17.4 %)	(62.4 %)			(100 %	(100 %)	(17.4 %)	(35.3 %)	(1.4 %)	(3.8 %)
2.	Kerosene (l)	298	452	4.22	5.72	250	385	127	285	108	156
		(75 %)	(58.9 %)			(83.9 %)	(85.2 %)	(42.6 %)	(63.1 %)	(36.2 %)	(34.5 %)
3.	Firewood (kg)	346	354	202	72.5	293	225	293	316		
		(87.2 %)	(46.1 %)			(84.7 %)	(63.6 %)	(84.7 %)	(89.3 %)		
4.	Crop waste (kg)	256	115	41.5	6.4	208	78	183	110		
		(64.5 %)	(15 %)			(81.3 %)	(67.8 %)	(71.5 %)	(95.7 %)		
5.	Biogas (m^3)	6	24			6	24	5	20		
		(1.6%)	(3.0%)			(1.6%)	(3.0%)	(1.3%)	(2.5%)		

proportion of households using hot plates (26.8 %), StWHs (30.6 %) and IWHs (35.5 %) are not very high in the AEH households as seen from the earlier result (cf. Table 2). There is also some mention of the use of biogas in non-AEH households (about 3 %) for both cooking and water-heating.

In the rural/urban classification (Table 12), only 17 % of the households in the rural areas use LPG whereas in the urban region the figure is 62 %. 75 % of the rural households use kerosene compared with 59 % of the urban households. 87 % of rural households use firewood as against 46 % of the urban households.

4.12. Penetration of energy-efficient devices

The energy-efficient devices considered for this study are fluorescent tubes (FTs), electronic chokes for them, reflectors for incandescent bulbs and electronic regulators for fans. It is found that on an average 21.2 % of the lamps (i.e., 1 out of 4.71 lamps) in a non-AEH household and 42.78 % (i.e., 4.09 out of 9.56 lamps) in an AEH household are FTs. Electronic chokes (ballasts) show very low penetration – they make up only 3.3 % of all chokes in AEH households and 0.8 % in non-AEH households. The reasons for this low penetration may be (1) the higher initial cost of electronic chokes compared with

electromagnetic chokes and (2) the low awareness level regarding electronic chokes. Larger proportions of AEH households (40.7 %) are using reflectors for their lamps than non-AEH households (12.7 %). Also, urban households are using reflectors more than rural households. Only AEH households use electronic regulators for fans and their penetration is nearly 8 %.

5. Conclusion

The present household survey of electricity consumption in four districts of Karnataka has revealed the pattern of consumption of electricity in AEH and non-AEH households, the stock of electrical appliances used by the households, the consumption of electricity in urban and rural areas, the use of non-electrical sources of energy for domestic purposes and the degree of penetration of energy-efficient appliances/devices.

The engineering approach of estimating the electricity consumption on the basis of the wattage of the appliances and the user's estimate of the hours of usage is unsatisfactory. This is because the estimated electricity consumption when regressed on the actual consumption of electricity in AEH and non-AEH households yields R^2 values of only 0.37 and 0.04 respectively. Nevertheless, the approach indicates that 79.69 % of the electricity consumption in an AEH household is due to lamps, water-heaters (IWHs/StWHs), hot plates, fans and refrigerators. In contrast, 83.38 % of the electricity consumption in a non-AEH household is due to lamps, fans, televisions and electric irons.

The appliance stock approach of estimating electricity consumption has indicated that a unit (kW) increase in load would result in an increase of 251.4 kWh per year in the electricity consumption, assuming a coincidence factor of unity.

The step-wise regression analysis in the appliance census approach has resulted in twelve categories of appliances explaining 62 % of the variation in the electricity consumption of AEH households and 9 categories of appliances explaining 31 % of the variation in the electricity consumption of non-AEH households. The estimated appliance elasticities show that an increment of unit percentage of appliance penetration would result in an increase of annual electricity consumption of 31.69 kWh for fans, 2.86 kWh for hot plates, 2.59 kWh for FT40s, 2.29 kWh for IL60s, and 1.86 kWh for IWHs in an AEH household. Similarly, for a non-AEH household, the annual increase would be 1.53 kWh for IL60s, 0.54 kWh for fans and 0.41 kWh for televisions.

The end-use analysis of electricity consumption in AEH households has shown that the consumption of electricity is mainly due to lighting (27.98 %), air circulation (23.42 %), water heating (18.13 %) and cooking (14.20 %). In non-AEH households, the end-uses accounting for most of the consumption of electricity are lighting (39.43 %), entertainment (23.97 %) and air circulation (20.76 %). The end-use analysis of electricity in the residential sector for the whole of Karnataka has shown that electricity is used mainly for lighting (32.28 %), air circulation (22.31 %), water-heating (11.09 %), entertainment (9.68 %) and cooking (8.69 %).

The end-use analysis of electricity in the residential sector has shown that electricity is used mainly for lighting, air circulation, water-heating, cooking and entertainment. The survey has also yielded the appliance elasticities which show the effect of unit percentage increase of appliance penetration on the annual electricity consumption. Interventions to influence electricity consumption without decreasing the energy services provided by electricity must focus therefore on devices for lighting, air circulation, water-heating, cooking and entertainment.

It is probably appropriate to mention here that the penetration of FTs is quite low in the rural and in the non-AEH households (sample mostly taken from the semi-urban areas). This is attributed mainly to the quality of power supply. (In low-voltage conditions, which are common, the FT fails to light up.) Hence it is important for policy-makers to understand these problems before promoting energy-efficient devices.

Apart from electricity, households use LPG, kerosene, firewood, crop waste and biogas for cooking, water-heating and lighting purposes. The results indicate that usage of kerosene, firewood and crop waste (mostly used for cooking and water-heating) is significant in non-AEH households. Even AEH households have reported the use of kerosene and fuelwood for cooking and water-heating. This result indicates a shift in the fuel source used for different applications so that it helps in forecasting the requirements for different energy sources.

Only a very small proportion of households have installed energy-efficient devices such as FTs and electronic chokes. Thus, there is tremendous scope for the use of energy-efficient devices by households. Steps have to be taken by the key actors such as the government, manufacturers, financial institutions, and electricity utilities to educate people and promote the usage of these devices in order to reduce unnecessary consumption. ■

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Notes

1. An all-electric home (AEH) is one in the 15-amp current rating category (corresponding to a 3.5 kVA connected load) and using both lighting and heating devices.
2. A non-all-electric home (non-AEH) is one with a 5-amp current rating corresponding to a 1.15 kVA load and mostly using lighting (and other low-wattage) devices only.
3. The survey was conducted by engineering students in Tumkur, Bijapur and Uttara Kannada districts. Only in Bangalore district, the survey was conducted with the assistance of an engineering graduate. The students of Sri Siddartha Institute of Technology, Tumkur, presented the survey results as a project report entitled "Household energy consumption survey" in partial fulfilment of their bachelor's degree. The project was jointly financed by IEI and the Karnataka State Council for Science and Technology (KSCST).
4. The reason for the somewhat low R^2 value was discussed with N. Krishnaji, Senior Fellow, Centre for Economic and Social Studies, Hyderabad, who suggested this as the main reason.

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Appendix A. Approaches to calculating household energy consumption

A1. Engineering stock approach

The engineering approach is based on the number of appliances, X_{ij}, the wattage, W_{ij}, and hours of usage, h_{ij} of the appliance j reported by the sample household i during the survey. The total electricity consumption in a household i can be related thus to the appliance-wise consumption:

$$E_i = \sum_j E_{ij}$$

where E_{ij} is the electricity consumed by the jth appliance in the ith household. Also, in the ith household,

$$E_{ij} = X_{ij} \times U_{ij}$$

where Uij is the electricity consumption of the jth appliance category and X_{ij} is the number of electrical appliances in the jth category. U_{ij} can be written as

$$U_{ij} = W_{ij} \times h_{ij}$$

where W_{ij} the wattage of the jth appliance category and h_{ij} is the number of hours per month for which the jth appliance is being used. U_{ij}, referred to as the engineering estimate of the appliance consumption, depends upon the accuracy of determination of the hours of usage. Substituting U_{ij} in the previous equation, the following expression is obtained for the electricity consumption of the ith household:

$$E_i = \Sigma_j X_{ij} \times W_{ij} \times h_{ij}$$

A2. Appliance stock approach

In determining electricity consumption in a household its stock of electrical appliances evidnetly plays a major role. If X_{ij} and W_{ij} are the number and wattage of electrical appliances of the jth category in the ith household, then $X_{ij} \times W_{ij}$ would be the electrical load in watts due to this category of appliances. It follows that $L_i = \Sigma_j (X_{ij} \times W_{ij})$ must be the total electrical load in watts due to this category of appliances. It is reasonable to expect that the electrical energy consumption E_i (in kWh) of households is correlated with their loads L_i (in kW).

A3. Appliance census approach

In the appliance census approach the relationship used to estimate the monthly electricity consumption of the jth appliance category is given by

$$E_i = \sum_j X_{ij} \times b_j$$

where b_j, the consumption per appliance of the jth category, can be estimated by regressing the electricity consumption E_i on the number of appliances X_{ij} of the jth category in the ith household. It must be noted that the coefficient b_j is not the consumption per appliance; it is the marginal consumption of the jth appliance category, i.e., the increase in consumption resulting from the addition of one appliance of the jth category. The marginal and the average consumption of the jth appliance category can be taken to be identical, as one expects a linear relation between the consumption and the number of appliances of a particular category.