A Study of Household Energy Consumption in Thimphu: Bhutan

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Abstract: A study to ascertain energy consumption pattern by household sector in urban region of Bhutan was conducted in Thimphu, Capital City of Bhutan, in 2017. Questionnaire was developed on the use of various forms of energy sources namely, electricity, liquefied petroleum gas, kerosene and firewood on energy consumption by different end-use applications in a household. From the 525 household respondents, it was found that electricity (59.69%) is the most preferred household energy mix, followed by liquefied petroleum gas (22.31%). Highest energy mix was consumed by space heating end-use (38.58%), pursued by cooking (29.65%) of the total final energy mix consumed in the household sector because: *Bukhari* (Traditional metal oven fed with biomass) and kerosene heater were also used beside electrical heaters for space heating, while cooling load was negligible. On the total share of electricity consumption, 34.47% was consumed for space heating, followed by 20.69% for hot water supply and least, 4.04% on entertainment. Above 90% of the household owned and used appliances like rice cooker, water boiler, television and refrigerator indicating consumer preferences towards electrical appliances and fuel choice. On average, a household here consumes approximately 4,500 kWh per year and spends BTN 1200 (1USD=64BTN, Bhutanese Currency Ngultrum) in winter and BTN 600 in summer month on electricity. Operating time and penetration of appliances are the main characteristics that attributes to the disparity in energy consumption under different income classes. Adoption of energy efficient technologies in probable end-use application would bring in considerable energy saving in household energy consumption and similar future study would determine the impact on implementation of such efficient technologies.

Keywords: Bhutan, Urban Household, Energy Consumption, Bukhari, End-use, Income Class.

1. Introduction

Globally, the Energy consumption has increased rapidly over the years and will continue to rise further. This is basically attributed to the rapid urbanization, technological development, ability of the people to pay more and overall increase in human population. The per capita energy consumption in most of the developing countries has increased substantially, particularly in sectors like, commercial, transport, industrial, and residential [1-2]. An increase in energy consumption is one of the key factors responsible for the global warming and greenhouse gas (GHGs) emission.

A study carried out by Irimiya et al. [3] have had predicted that primary energy consumption globally will grow almost by 50% from 2003 to 2030. The International Energy Outlook 2016 (IEO2016) reported that, the building sector worldwide, comprising of residential and commercial end users, accounted for 20.1% of the total energy consumption which is expected to increase by an average of 1.5% annually from 2012 until 2040, while an annual growth by 0.6% per year in the Organisation for Economic Co-operation and Development (OECD) countries and by 2.1% per year in non-OECD countries is presumed from 2014 [4].

Unlike in developed countries, households in the developing countries such as Bhutan, mostly rely on biomass (fuel-wood) as main the primary source of energy; especially for cooking and space heating, rather than other sources of energy. Perhaps, this would be basically due to an easy accessibility of fuel-wood in proximity or lack of their affordability to clean energy source. Besides, in the developing countries, most household have their socioeconomic, cultural and environmental barrier in changing their energy-use patterns [5-6].

The study area of Thimphu, the capital city of Bhutan is located at 27.4728 ° N, 89.6393 ° E at an elevation of 2,334m (above mean sea level) having an area of 26 sq.km extending from Dechenchholing in the North to Babesa in the South along the River *Wang Chhu*. The city has a total population of about 104, 200 with about 24, 971 households [7]. Hydroelectricity is the primary source of energy here, while Liquefied Petroleum Gas

LPG, kerosene and firewood are also being consumed for different end-use application by the households (HH).

Households in Bhutan commonly use biomass which constitute about 87% followed by electricity (8%), LPG (3%) and kerosene (2%) of the total fuel mix composition. This is basically that the rural households still rely on biomass (firewood and briquettes) while urban households largely depends on electricity and the LPG. In 2014, the building sector in the country consumed about 270, 356 tonnes of oil equivalent (TOE) of energy, which was 41.58% of total final energy consumed in the country out of which residential segment consumed about 213,422 TOE of final energy. Bhutan domestic electricity consumption has increased by Compunded Annual Growth Rate (CAGR) of about 10.1% from 2005 to 2014 [8]. Similarly, the current study found out that the households in the capital City Thimphu had consumed about 14,035.54 TOE of total final energy in 2017; hydroelectricity at 59.69% was the highest of all fuel composition followed by LPG, Biomass and kerosene, 8.72% as depicted in Figure 1. Thimphu City being the capital consumed the highest quantity of energy as compared to rest of the cities in Bhutan. Consumption of total fuel mix in Thimphu City have increased by 5.65% CAGR from 2014 to 2017.

Space heating dominates the consumption of fuel by end use in the cold countries. The previous studies [9,5] illustrated that household size, occupant's age, household income and educational level are some of the attributes related to energy consumption variance in any household. While it is presumed that households tends to consume more energy due to easy accessibility, affordability, lifestyle, consumer behaviour and perhaps, the lack of conscience and advocacy on energy efficiency and sustainability. Laicane et al [10] have found out that almost 20% energy could be saved by changing the lifestyle and consumer behaviour.

Similar studies at a national and a regional levels have been carried out in different countries of the world and similarly it is crucial for Thimphu city. The importance of focusing this study in Thimphu is basically, Thimphu being the Capital City is still at an infant stage and is also the fastest growing City in the region with higher population density, and the people come from

all walks of life. Bhutan exports its excess generated hydropower to India during the peak monsoon season, while the Country has to import deficit power during lean winter season when generation is low due to low river volume but have high energy demand in the Country during this season, especially higher in Thimphu. The usual winter periods import is about 160 GWh which is expected to grow by 25% annually [11-13]. World average per capita electricity consumption is about 3,500 kWh and Bhutan per capita electricity consumption is almost in par with world's average (3,400 kWh). The United States of America consumes almost 12,000 kWh, while China and India the neighbouring countries consumes about 4,300 kWh and 820 kWh respectively [14,15]. The study would provide a tool for policy makers to draw in useful policies and additionally it will also provide a path for future researchers to carryout similar studies at the sub-regional level and compare with the consumer behaviours which may be useful in developing sustainable energy policy in Bhutan.

The study aims to understand household energy consumption patterns under different consumer categories by various end-use applications, their behaviours, knowledge on energy saving and energy efficient technologies. Additionally, study delves on the share of household expenditure by electricity consumption and draw in recommendations on energy savings by implementing efficient technologies.

2. Experimental

2.1 Data Collections

Household survey in Thimphu was conducted to collect the primary data on household end-use applications. The survey questionnaire had four Sections: A) General household information, where respondent were asked about the household members, number of children and elderly persons in the house, the annual household income and dwellings type; B) Constituted common household electrical appliances divided under various end-use. Here, the information like number of appliances owned by HH and hour of operation in a day was sought; C) was on non-electricity fuels namely, kerosene, LPG, biomass (firewood and briquette) use for space heating and cooking end-uses; and D) was framed to find out about the household's advocacies on energy saving practices and energy efficient appliances.

In Section B, the appliances were categorized under seven different end-use based on their function and usage purpose at home, namely cooking, hot water supply, space heating, lighting, entertainment, refrigeration and other appliances. Appliances like washing machine, electric iron, hair drier, grinder, blender, toaster and other common household appliances used in kitchen are kept under end-use 'other appliances' because, most of these appliances are hardly being used on daily basis.

Yamane equation was use to determine the sample size and field survey comprising a total of 524 samples were randomly collected from among the households in Thimphu City. The questionnaire sample was categorized under five different income groups based on the annual household income as indicated by respondent which is indicated in Table 1. For the purpose of this study, ratio of number of household population falling under each

income group have been derived based on number of samples in each income classes. The income bracket classification had been taken from the personal income tax (PIT) filing, adopted by Department of Revenue and Custom, Ministry of Finance, Royal Government of Bhutan (DRC, MoF, RGoB) [16]. Secondary data on domestic electricity consumption were collected from the Bhutan Power Corporation Limited (BPC) to support the findings. Further, secondary data on hydropower generation, demography, GDP and other information were collected from various agencies namely; Druk Green Power Corporation (DGPC), Department of Hydropower and Power System (DHPS), National Statistical Bureau (NSB), Department of Renewable Energy (DRE), National Resources Development Corporation Limited (NRDCL).

2.2 Household Energy Consumption using End-use Model

Household energy consumption was calculated by using bottom-up end-use model which relies on power rating, operating time, number of appliance in use, and penetration. To determine household electricity consumption by the appliances in various income categories, energy demand in household sector E_{HH} (kWh) was calculated using the following equation [15-17].

$$E_{HH} = \sum_{i=1}^{n} \sum_{i=1}^{m} N_{i,j} P_{i,j} M_{i,j} I_{i,j} \qquad (1)$$

Where:
$N_{i,j}$ = the total number of HH with end-use $'i'$ in income class $'j'$,
$P_{i,j}$ = penetration level of appliance for end-use $'i'$ in income class $'j'$,
$M_{i,j}$ = operating time of an appliance $'i'$ in income class $'j'$ (hours),
$I_{i,j}$ = intensity of appliance $'i'$ in income class $'j'$ (watts)
i = end-use device, $i = 1,2,3,\ldots\ldots,n$
j = income class, $j = 1,2,3,\ldots\ldots,m$

In reality, the rated power of some of the appliances like refrigerators, rice cooker may not be consumed during its operation. Therefore, in order to arrive at a concise result, a coefficient $R_{i,j}$ for some known appliance were used in the above equation to derive the final result. Where, $R_{i,j}$ is the ratio of actual power consumed to rated power of the appliance $'i'$ in income class $'j'$ during its operation.

$$E_{HH} = \sum_{i=1}^{n} \sum_{i=1}^{m} N_{i,j} P_{i,j} M_{i,j} I_{i,j} R_{i,j} \qquad (2)$$

The coefficient depends on performance of the appliances, which further depends on the climatic condition of the area of use. For the purpose of this study, the value 0.36 is adopted for refrigerator [20] and 0.9 for hot water geyser and water boiler, whose energy factor (EF) range falls between 0.86 to 0.96 [21]. For rice cooker, the operating time was divided into full load operation, while cooking and standby (while keeping warm), to derive the coefficient. It was assumed that 50% of operating time consumes rated power while the remaining 50% would operate at 20% of rated power capacity.

Table 1. Income Distribution Classification.

No.	Income Class	Range (BTN)[a]	Sample Household
1	Low income	Less than 100,000	56
2	Low-middle income	100,000 to 250,000	190
3	Middle income	250,000 to 500,000	191
4	Upper-middle income	500,000 to 1,000,000	68
5	High income	Above 1,000,000	19
	Total Sample		**524**

[a] Bhutanese Currency Ngultrum (1USD = 64 BTN)
(Source: DRC, MoF, RGoB)

3. Results and Discussions

Thimphu is the Capital City of Bhutan covering an area of 26 sq.km and having a population of 104, 200 and 24,917 households. The study depicated that electricity was the primary energy source for all segment of household followed by LPG while, kerosene and biomass (firewood) are also being conumed which constitute 8.72% and 9.28% respectively of the total fuel mix (Figure 1).
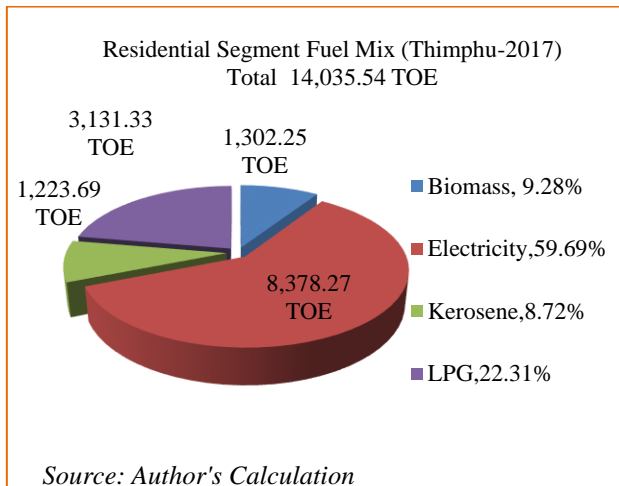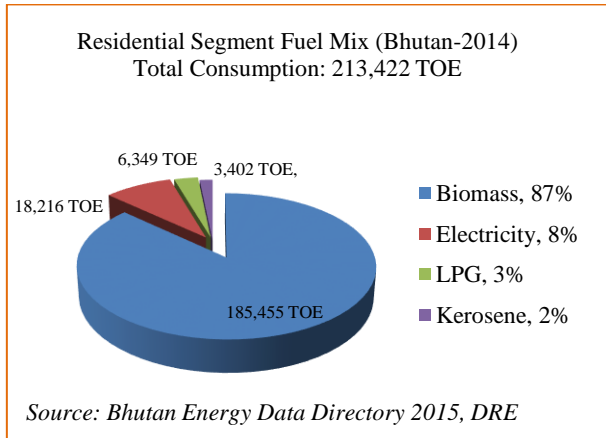

Figure 1. Residential Segment Energy Consumption Fuel Mix Split: Bhutan in 2014 and Thimphu in 2017, a Comparison.

Total final energy consumption in a household in Thimphu City was computed based on the household survey data received from household respondent samples, randomly collected from all section of the population and the total population was divided into different income class based on their annual income and were grouped on the basis of ratio of sample collected. Figure 2 shows that electricity was the most preferred energy source. Highest percentage of electricity in a household was consumed by space heating end-use 34.47% followed by hot water supply 20.698%, cooking 12.28%, lighting 12.12%, other appliances 8.65%, refrigerator 7.75% and entertainment 4.04% as shown in Figure 3.

The study indicated a similar trend amongst all income levels. While it is evident that space heating end-use constitutes highetst of the total fuel mix share (38.58%) followed by cooking (29.65%) and hotwater supply (12.35%) end-use as shown in Figure 3, because, Bukhari and kerosene heaters (Figure 4) operating with firewood and kerosene respectively are also being used in addition to electric room heater as indicated in Figure 2. The average months for the operation of space heating appliances was four months (November to February), while hotwater is

being used almost throught the year. On the other hand, for cooking 29.65% of fuel mix constitutes LPG 75.27% and electricity 24.73% respectively of the total cooking fuel and the households depends on both fuels almost equally.
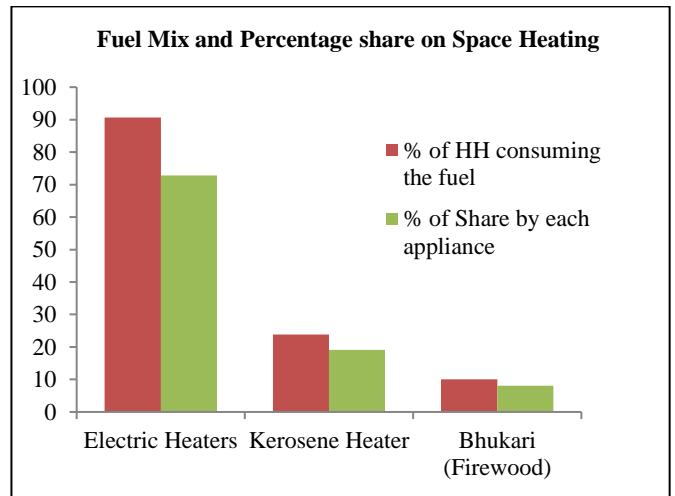

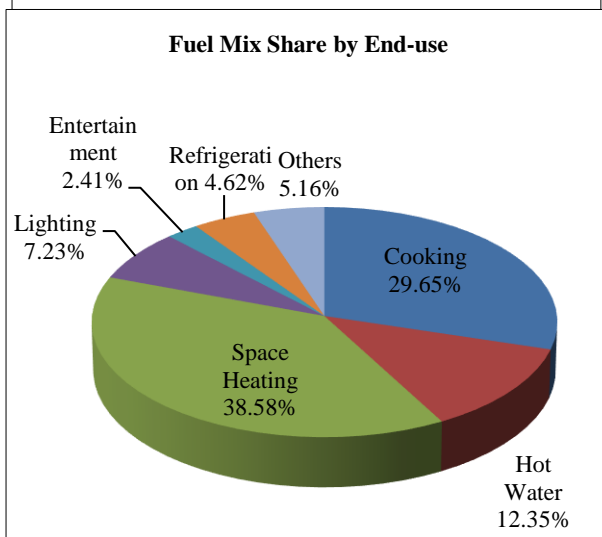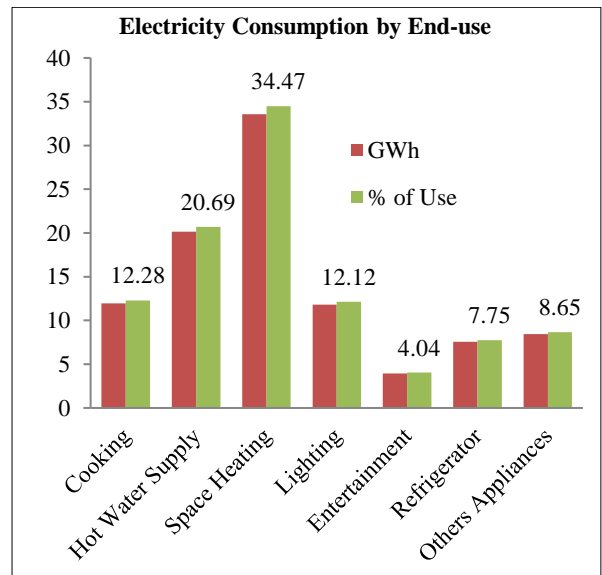**Figure 2.** Household Fuel Mix Consumption and Percentage Share by Appliances for Space Heating.

Figure 3. Electricity Consumption and Fuel Mix Share by End-use.

Figure 4. Bukhari[b] and a Kerosene Room Heater used in Bhutanese House.
[b] Traditional metal oven fed with biomass (fuel-wood)

Figure 5. Household Average Annual Electricity Consumption by End-use Under Different Income Level (kWh/year/HH).

Figure 6. Average Household's Annual Fuel Mix Consumed by Income Class (TOE).

Figure 7. Comaprision of Fuel Mix Consumption by Household in 2014 and 2017
(Source: Bhutan Energy Data Directory 2015, DRE, MoEA for 2014 Data)

Average household electricity consumption in Thimphu is about 4,500 kWh per year which is about 1,097 kWh/person higher than that of India. Figure 5 illustrates that a household under high income category consumed an average of 6,479 kWh/year/HH (kWh per year per household) of electricity, while the lowest income household consumed the lowest of all, 3,246 kWh/year/HH. The result also indicates that electricity consumed by a household under low-middle and middle income are almost same and this two income groups dominates the total urban population. Electricity consumption rises as the income rise and the trend for each end-use applicaiton are similiar in nature. The result had been derived based on the median value of hours of appliance operation under each income class and the operating time of appliances shows a small difference between household's income levels. Although there is small variation from low to high income class, the result in generic supports the previous studies which confirmed that, higher the household income, higher the energy consumption. A little divergence in the result for some end-use appliations could be due to their range of dwelling type and fuel preferances, as other household characteristics.

Comparatively, household under the low income segment show higher electricity consumption in cooking end-use although both fuel are used almost at par. The, more dependency on electricity rather than LPG could likely, because of cheaper and more reliable electricity supply. Conversely, it becomes expensive and time consuming to fetch LPG cylinder due to depot's distant location and availability. In the entire income level, not much variation in the burning up of LPG and firewood was seen, while more kerosene was consumed by lower-middle income household, offsetting the use of fuel wood as indicated in Figure 6 below.

The households in the Capital had consumed a total of 14,035.54 ToE of final energy in 2017, which is 5.65% Compounded Annual Growth Rate (CAGR) from 2014. Figure 7 below shows a rise in the consumption of electricity, LPG and kerosene, while it indicated a fall in the consumption of biomass during the same period. Firewood supply record from NRDCL shows that a decrease by 6.1% of its supply in 2016 from 2015, while there was a 12.5% increase in 2015 from 2014. The discrepancy between the results could likely be that most of the households use the fire wood that was stored from previous year's supply, while storing the fresh supply allowing it to get dried for use in the subsequent years. Further, the firewood bought in a season will not be consumed completely hence, the result between supply and consumption always differ.
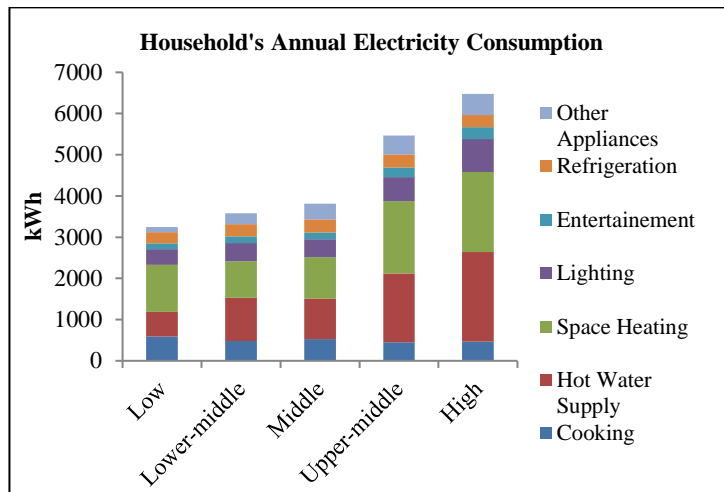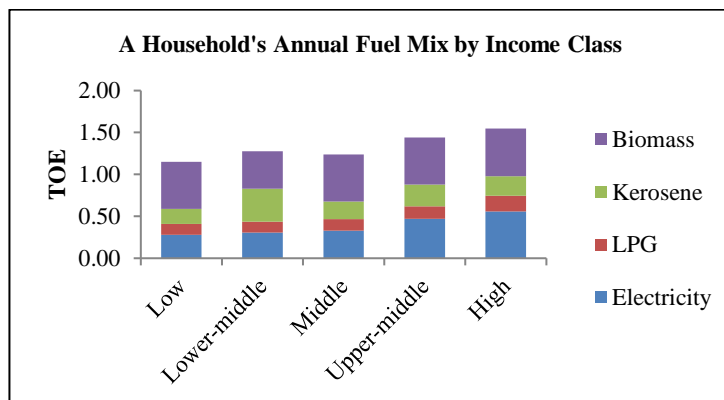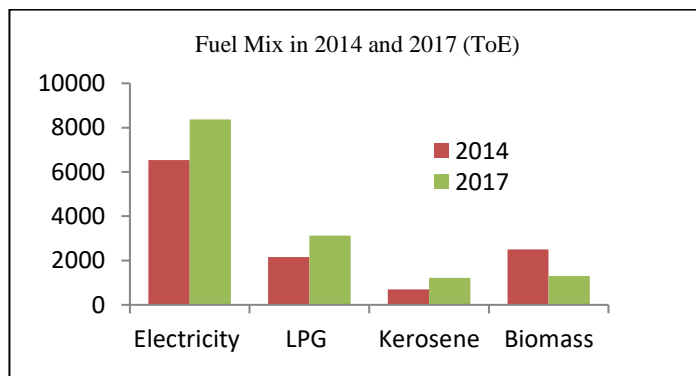
Table 2 illustrates that rice cookers have the highest penetration into the society. Perhaps, this could be basically due to its affordability, reliability and meliorate in preparing and keeping meal warm for long hours and is therefore, preferred for the working population. While the induction cooking plate has not become a preferable choice as of now, the coil electric cooking stoves has now become obsolete and is seldom used in the urban households. Water boilers are preferred to electric kettles. However, electric kettles are also picking up in the market lately, and hot water geysers are more commonly used by upper-middle

and high income groups as compared to that the low and lower-middle income groups. The result shows a large penetration gap of 0.36 to 0.95 in owning and use of washing machine from low to high income level, while television and refrigerators are owned almost equally by all households of the entire income group.

The study found that most of the households in the low and lower-middle income bracket do not own many of the household appliances such as grinder, blender, microwave, electric iron etcetera. The reasons could be its functionality, preferences to use, usability, affordability and most probably acceptance to use. Although, the households in the upper income class do own most of these appliances, they are seldom being used, which indicates that the appliances do not really make a huge implication to the society. Similarly, usage of fans are very minimal despite household owing them, because of moderate summer months.

On an average, a household spend about BTN 600 per month in summer and BTN 1,200 per month in winter on electricity. The maximum amount spend by an individual was as high as BTN 3,000 and BTN 8,000 per month, while minimum was BTN 45 and BTN 200 for summer and winter months respectively.

The major differences in energy consumption between various income levels were the operating time. Households at the upper income class tend to use the appliances for more number of hours as compared to their lower groups, while variation in consumption of forms of fuel, especially for space heating, is redeemed each other by either of the fuels.

The higher share in electricity use by population is basically that Bhutan has over 95% access to electricity and Thimphu City has 100% household electricity connectivity [22]. Consumption of fuels like LPG and kerosene are also revealed to be rising annually which can be attributed to easy accessibility and subsidy provided by the Royal Government. On the other hand, there has not been much variation in the consumption of firewood in the capital as it could possibly be due to building owner's choice. Building owners do not prefer providing a smoke chimney for the use of *Bukhari* during construction of building apartments and consequently, it is only those residing in old structures who are potential users of *Bukhari*. This might also be the reason as to why there has been an increase in use of electrical and kerosene space heating appliances.

Table 2. Penetration and Operating Time Household Electrical Appliances by Income Level.

End-use Application	Appliances	Intensity (W)	Penetration of Appliance					Appliance Operating Time per Month (hour)				
			Low	Lower-middle	Middle	Upper-middle	High	Low	Lower-middle	Middle	Upper-middle	High
Cooking	Rice Cooker	500	0.96	1.00	1.00	0.97	1.00	90	90	90	90	90
	Curry Cooker	1000	0.70	0.64	0.57	0.43	0.74	30	15	20	8	8
	Induction Plate	2000	0.14	0.11	0.17	0.24	0.16	8	15	15	15	15
	Electric Stove	1500	0.02	0.05	0.05	0.10	0.16	0.5	8	6	4	4
Hot Water Supply	Water Boiler	750	0.96	0.94	0.90	0.91	0.95	30	45	45	60	45
	Electric Kettel	1500	0.21	0.24	0.26	0.22	0.42	15	15	15	15	15
	Hot Water Geyser	2000	0.27	0.46	0.69	0.82	0.84	24	48	32	60	90
	Immerion Water Heater	1500	0.29	0.36	0.36	0.38	0.37	15	15	12	12	12
	Home-made Water Heater	1500	0.32	0.28	0.18	0.12	0.11	15	12	8	8	0
Space Heating	Single Rod Room Heater	1000	0.14	0.16	0.14	0.15	0.05	180	120	90	180	90
	Double Rod Room Heater	2000	0.38	0.01	0.01	0.34	0.11	150	120	120	180	90
	Blower Heater	1500	0.05	0.09	0.08	0.19	0.16	60	120	90	150	150
	Halogen Heater	2000	0.45	0.48	0.48	0.44	0.42	120	150	150	150	300
	Oil-filled Radiator (6 fins)	1000	0.04	0.05	0.18	0.21	0.16	90	150	180	150	300
	Oil-filled Radiator (12 fins)	2000	0.11	0.10	0.14	0.24	0.42	150	150	180	180	150
Lighting	Incandescent Lamp	60	0.46	0.42	0.49	0.29	0.53	240	240	180	120	600
	Incandescent Lamp	100	0.30	0.27	0.21	0.24	0.16	240	240	300	360	360
	Fluorescent Tube Light	20	0.13	0.16	0.30	0.32	0.47	300	240	300	720	450
	Fluorescent Tube Light	40	0.80	0.87	0.69	0.76	0.84	450	600	720	900	900
	Compact Fluorescent Lamp	9	0.14	0.18	0.26	0.19	0.32	360	300	360	960	480
	Compact Fluorescent Lamp	12	0.29	0.36	0.34	0.41	0.37	360	240	240	300	540
	Compact Fluorescent Lamp	18	0.16	0.15	0.16	0.15	0.26	360	300	360	720	720
	Light Emitting Diod	9	0.11	0.09	0.15	0.29	0.11	240	600	300	360	420
Entertainment	Television	60	0.93	0.95	0.98	0.94	1.00	180	150	150	240	240
	Laptop	65	0.27	0.63	0.76	0.78	0.84	30	60	60	60	60
	Desktop Computer	100	0.11	0.19	0.19	0.29	0.37	30	60	30	30	90
	CD/DVD Player	30	0.21	0.15	0.14	0.24	0.26	12	12	8	8	15
	Tablet	15	0.21	0.19	0.40	0.56	0.42	90	120	60	90	90
	Radio	30	0.11	0.08	0.06	0.12	0.21	24	30	15	45	30
	Video Games	190	0.02	0.11	0.10	0.19	0.32	36	36	36	30	36
Refrigeration	Refrigerator	105	0.82	0.91	0.97	0.96	0.89	720	720	720	720	720
Other Appliance	Washing Machine	500	0.36	0.67	0.79	0.87	0.95	16	24	30	30	30
	Microwave	1500	0.16	0.30	0.49	0.68	0.74	15	15	15	15	15
	Ceiling Fan	80	0.07	0.04	0.10	0.16	0.26	30	30	30	60	30
	Table/Pedestal Fan	80	0.20	0.19	0.16	0.26	0.26	30	30	30	30	30
	Exhaust Fan	60	0.14	0.27	0.49	0.53	0.53	15	30	30	30	30
	Grinder/Juicer	500	0.29	0.40	0.57	0.63	0.68	4	4	4	4	6
	Hand Blender	200	0.27	0.49	0.49	0.50	0.42	4	1	4	4	4
	Bread Toaster	850	0.05	0.17	0.28	0.41	0.37	4	4	4	4	4
	Electric Iron	1000	0.29	0.45	0.64	0.68	0.89	4	4	4	4	4
	Hair Drier	1200	0.36	0.53	0.62	0.71	0.79	4	5	4	4	4

Table 3. Scenairo after Implementing Energy Efficient Technology in Domestic Lighting.

Luminaires Description	Quantity	Existing Scenario		EE Scenario	
		Rating (W)	Total Power (W)	Rating (W)	Total Power (W)
Fluroscent Tube Light (T12)	10	40	400	18	180
Surface Ceiling Light	4	60	240	12	48
Wall Bracket	4	100	400	18	72
Mirror Light	2	60	120	9	18
Total (W)			1160		318
Saving (%)					72.59

(Source: Author's assumption and assessment)

The study indicated that about 25.52% of the HH are still unaware of energy efficiency, while 18.81% of HH do keep their lights "ON" during daytime. It is done either intentionally due to insufficient daylight entering the room or because of room orientation and poor design or done inadvertently by the occupants. Although, majority of the HH have already started using energy efficient luminaires indicating acceptance to change, a substantial difference on energy saving could not be realized unless the entire non-efficient, obsolete luminaires are either replaced or retrofitted with energy efficient technologies. Table 3 above exemplify almost 73% energy saving on domestic lighting could be achieved from a typical three bed room apartment on implementation of EE and gradually similar EE technologies could be implemented for probable appliances like refrigerator, room heaters, and tank hot water geysers. Besides, advocacy on energy sustainability and energy efficiency should be carried out extensively so that it reaches to all levels and strata of the society. However, the government must come up with strong policies and regulations so that the consumers at all levels accept the new technological innovation without much resistance.

4. Conclusion and Recommendations

The study on the household energy consumption was conducted only for Thimphu City to analyse energy consumption pattern by different consumer groups in the capital city. The common household appliances were choosen to ascertain the energy consumption scenario. As the household income ladder rise from low to high income, significant difference had been observed in terms of electricity usage, whilst not much variation was found between the lower-middle and middle income groups. Exploitation of conventional fuels like, LPG and kerosene also did not have momentous variation in their usage and have had been offset by eachother. In addition to electricity, firewood and kerosene are the fuel choice for space heating, while higher preferances was for electricity. Although, there was considerable difference between low and the high income household, there was not a vast gap for the lower-middle and middle income class households. Hence, the past study somehow substantiate the study however, it still gives a room for future researcher to study further on electricity consumption by electrical appliances using onsite testing instrument and look into different aspect for fuel choices in their houses.

This study observed that operating time of appliances, penetration of apliances (Table 2) and applaince preferences, especially for the space heating, hotwater supply and cooking were the areas for variation in energy consumption and fuel choice by households under different income classes, which also attribute to difference in energy cost. The existing trend indicates that energy consumption at the household levels have been rising and will continue to do so. Therefore, adoption of energy efficient technologies in probable end-use application would bring in considerable energy saving in household.

Bhutan is the only country declared as *"Carbon Negative"* because of higher carbon sequestration by its pristine environment than it generates[23]. Therefore, in order to maintain carbon negative in all times to come, and to be energy sustainable, the government should develop certain stringent energy efficient policies. The Royal Government of Bhutan has already started taking initiative towards energy efficiency and conservation and the energy policies are already in the pipeline which needs adopted meaningfully.

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