ICONARP
International Journal of Architecture and Planning
Received: 20.07.2024 Accepted: 30.10.2025
Volume 13, Issue 2/ Published: 31.12.2025
Research Article *DOI: 10.15320/ICONARP.2025.333 E- ISSN:2147-9380*
ICONARP

Development of Energy Consumption Profiles of Common Household Appliances by Analyzing their Energy Consumption

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Abstract

Residential energy consumption constitutes a major share of overall electricity demand, and inefficient use of household appliances, including hidden standby loads, which contributes to higher energy costs, wasted resources, and barriers to sustainable energy management. Addressing this requires accurate insights into how appliances consume energy in real-time, enabling more efficient strategies for household, utilities, and policymakers. This study conducted a comprehensive analysis of residential energy consumption by monitoring the real-time energy usage of common household appliances. The primary goal was to develop detailed energy consumption profiles that could benefit both researchers and distribution companies. To achieve this, the energy consumption data of various household appliances were recorded over a period of one month with a high time resolution of one-second intervals, utilizing smart plugs for wireless energy measurement. A significant focus of the study was to understand the impact of standby power consumption on overall energy use and efficiency. By accurately measuring appliance-level energy consumption, the study was able to create detailed profiles, which were then used to predict the energy use for the following month. The predicted total monthly energy consumption was validated against actual energy bills provided by the state electricity board, demonstrating the reliability and accuracy of the predictions. The collected data from this study offers a valuable database for identifying and understanding energy consumption patterns of household appliances, which is essential for residential energy management research. Further, the findings emphasize the significance of real-time monitoring in crafting effective energy management strategies. Such strategies can lead to more sustainable energy use, benefiting both consumers and energy providers. On a broader scale, this method can support economic development by enhancing energy efficiency and reducing waste. The study underscores the potential of detailed, real-time energy monitoring to improve energy policy and household energy management, paving the way for more informed and sustainable energy practices.

Keywords: *Alternate energy source, Energy consumption profiles, Energy efficiency, Energy management, Sustainable development goals*

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To cite this article: Nainwal, R., & Sharma, A. (2025). Development of Energy Consumption Profiles of Common Household Appliances by Analyzing their Energy Consumption. *ICONARP International Journal of Architecture and Planning,* 13 (2), 494-523. DOI: 10.15320/ICONARP.2025.333

INTRODUCTION

The United Nations (UN) General Assembly, in its 70th Session held on 25th September 2015, adopted the document titled "Transforming our World: The 2030 Agenda for Sustainable Development consisting of 17 Sustainable Development Goals (SDGs) and associated 169 targets (*Sustainable Development Goals, Department of Economic and Social Affairs, United Nations*, 2015). SDGs are a comprehensive list of global goals integrating social, economic, and environmental dimensions of development. Realizing that energy is critical for people deprived of the opportunity of access to sustainable energy, Goal 7 with the aim to ensure access to affordable, reliable, sustainable, and modern energy to all was adopted as one of the 17 SDGs. The goal also stresses more focused attention to improve access to clean and safe cooking fuels and technologies, improve energy efficiency, increase use of renewable sources and promotion of sustainable and modern energy for all (*Sustainable Development Goals, Department of Economic and Social Affairs, United Nations*, 2015).

If the world is to develop sustainably, it has been recognized that it is necessary to secure access to affordable, reliable, sustainable, and modern energy services while reducing greenhouse gas emissions and the carbon footprint of the energy sector (*Energy Statistics India*, 2022). Energy systems capable of delivering to the ever growing and emerging needs of developing economies is the need of the hour (*Energy Statistics India*, 2022). Growing energy demands over the world and in the densely populated regions of Asia including India have driven the need of larger energy systems (*Energy Statistics India*, 2022). Thus, in India, there has been a thrust to increase installed generating capacity of electrical energy. The availability of and access to energy and energy sources are particularly essential for poverty reduction and further improvements in standards of living (*Energy Statistics India*, 2022).

Demand response was first intended to be a shift in normal consumption demand that took into account a rise or decline in electrical energy production (Beaudin & Zareipour, 2015). To address this, nations such as the United States have implemented demand response programs, which were designed to provide economic advantages to customers and utilities while also improving the dependability and sustainability of electrical energy networks (Hurley et al., 2013; Shakeri et al., 2017). Many governments provide direct or indirect incentives to promote the employment of demand response systems. The European Union has adopted dynamic demand response programs as a strategic instrument to meet its three primary goals of a 20% reduction in greenhouse gas emissions, a 20% increase in energy production from renewable energy sources, and a 20% increase in energy efficiency (Agnetis et al., 2013). Although the amount of energy used in buildings varies by nation, it accounts for 30-40% of total global electrical energy usage (Zhang et al., 2013). According to the Indian Energy Statistics 2022, the major electricity (henceforth called as

DOI10.15320/ICONARP.2025.333

‘energy’) consumption sectors in India are industrial sector (41% of the total electricity consumed in the country), followed by residential sector (26%), Agricultural sector (18%), and commercial sector (8%) (*Energy Statistics India*, 2022). It is to be noted that around 34% of the total electricity consumption in India is being done by the building sector. The great majority of residential structures are unable to take advantage of demand response possibilities, despite their widespread usage by industrial and commercial establishments (Shirazi et al., 2015). The largest barrier to the introduction of demand response technologies in households is the substantial reduction in housing comfort and energy consumption behavior (Faruqui & Sergici, 2010). Yet, with the rise of internet and computer technologies, intelligent home energy management systems have become more popular in recent years with the purpose of improving the comfort of the house (Tang et al., 2017; Wu et al., 2018). Therefore, home energy management studies are essential to deploy the demand response solutions successfully in homes (Kuzlu et al., 2012). To comprehend how final demand influences energy consumption, it is essential to research energy consumption patterns in all economies (Kuzlu et al., 2012). Additionally, data on several consumption activities, such as building space heating and cooling and other, are needed for this.

The reliability of demand response studies is affected by the method used to ascertain the profile of energy usage in homes. Information on energy usage is essential for designing efficient distribution networks and giving more accurate results. When planning local demand side management (DSM) measures or properly sizing the small-scale distributed energy technology into the local network, accurate understanding of the residential consumer loads is essential (Paatero & Lund, 2006). In this way, numerous techniques were employed to accurately produce the load profile and energy consumption of residential appliances (Ahmed et al., 2015; Bissey et al., 2017; Pipattanasomporn et al., 2014; Tewathia, 2014). In the literature (Capasso et al., 1994), actual energy usage data of a house is commonly generated using the bottom-up technique. The bottom-up method's primary drawback is its dependence on precise energy consumption data (Angioni et al., 2016). To date, this issue has been addressed in several publications via the use of representative data and statistical averages of the use of electrical equipment. Using an energy cost meter, the standby energy consumption of several domestic appliances was assessed. It was discovered that standby energy consumption was higher than operational energy consumption. However, how the appliance was used and how long it was left in standby mode rely on the user's behavior (Ajay-D-Vimal Raj et al., 2009). Using the bottom-up methodology, the buildings in Singapore were categorized according to their energy consumption, and mathematical models and load profiles were created in (Chuan & Ukil, 2015). The generated load models were then compared to actual models, and homes were categorized according to the number of rooms within (Chuan & Ukil, 2015).

Using energy consumption data acquired of home appliances, electrical household equipment was quickly and accurately classified using machine learning methods in (Abeykoon et al., 2016). Although this modelling was successful for the great majority of devices, the devices with more complicated operating modes require more sample energy consumption and algorithm training to attain the same results. Using energy consumption data from 128 homes as training samples, a method was built in (Bennett et al., 2014) to predict residential building energy demand profiles. The system was created using information about typical energy consumption. The energy consumption data of two different houses for the typical household appliances was used to create energy consumption profiles in (Pipattanasomporn et al., 2014) and the potentials for energy demand management of these profiles were discussed. Although the study identified the primary energy consuming appliances in both homes, the sample size was not sufficient for the energy demand response research. The monthly energy consumption of household appliances was predicted using a multivariate regression analysis that took seasonality into account (Tewathia, 2014).

The study done by Czetany et. al. (Czétány et al., 2021) assessed the electric load dataset collected from more than the thousand households in Hungary, majorly single-family houses, and determined the energy consumption profiles using time series data of daily and annual electric load. Another study (Csoknyai et al., 2019) focuses on energy consumption habits in more than 150 residential buildings in France and Spain, using consumer feedback on smart metering. The study done by Cetin et. al. (Cetin K. S. et al., 2014) provides the energy consumption profiles of four major household appliances, i.e., refrigerator, clothes washing, clothes dryer, and dishwasher, through the data collected from 40 single family homes in Austin and concluded that the average load profiles of these appliances have the similar energy load distributions. The study done by Santin (Santin, 2011) determines the behavioural patterns associated with the energy consumption of space heating appliances. Another study done by Laskari et. al. (Marina et al., 2022) provided a quantitative assessment of the impact of different users and indoor environmental conditions on residential heating energy consumption. Another study (Firth et al., 2008) monitored the 72 residential units in 2007 in the five-minutes interval for a time-period of two years and the results showed that there was 4.5% increment in the overall energy consumption in second year because of the increase in standby time of the appliances. A measurement and control system for the electric energy consumption of home appliances was developed in (Kam et al., 2014). The study concludes that effective control of appliances can be done following the energy consumption prices. The above studies show the importance of energy consumption profiles of various appliances in the residential buildings sector. These profiles can

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extensively be used in energy demand management, achieving energy efficiency and formulation of time series data for further prediction.

There aren't many studies that concentrate on the data for energy consumption and particular energy consumption profiles of household appliances, even though they are needed in many places. This is the primary reason why, in past years, the standard energy consumption profile and average energy consumption of residential appliances were used. More accurate energy consumption profiles and statistics are required in the distribution system as new technologies and smart grids become more prevalent. The main objective of this study is to provide comprehensive information on residential energy consumption by monitoring the real time energy consumption data of typical household appliances and explain their energy consumption profiles, which will be useful for the researchers and distribution companies. Moreover, by evaluating the collected data, this research reveals the effect of standby consumption on overall energy consumption and efficiency.

For this, the energy consumption data of various household appliances used by a five-person family residing in Shimla, Himachal Pradesh, India, was recorded with high time resolution at one-second intervals during the month of December 2023, using smart plugs for wireless energy measurement. The exact energy consumption of household appliances was evaluated, and the energy consumption profiles of the equipment were developed. December was specifically chosen as the study period because Shimla, being a hilly region, experiences extremely cold weather and snowfall during winters. These climatic conditions lead to very high household energy consumption due to heating loads, whereas in summer the outdoor temperature is pleasant and only negligible lighting energy use occurs. Studying energy consumption during December therefore captures the period of maximum residential energy demand, making the results highly relevant for energy efficiency and demand management. The collected information is crucial since it may serve as a comprehensive database for the exact and correct identification of electrical household equipment for use in domestic energy management research. Therefore, a five-person family's energy consumption patterns in the climatic and geographic setting of Himachal Pradesh are shown in this study, which is a unique piece of research.

While previous studies have examined household energy consumption at varying scales, most have relied on aggregated consumption data, statistical averages, or low-resolution monitoring, which limits their ability to capture appliance-level variations and hidden loads. Moreover, limited attention has been given to cold climatic regions such as Shimla, where winter heating significantly alters residential energy demand. This study addresses these gaps by employing one-second interval monitoring of common household appliances, enabling the creation of highly detailed consumption profiles. Unlike prior work, the research explicitly quantifies the impact of standby power consumption, an often overlooked but critical contributor to energy inefficiency. Further, the reliability of the developed profiles is strengthened by their validation against actual electricity bills from the state electricity board. Through this approach, the study contributes to existing literature by providing a granular, climate-specific, and validated dataset that can inform demand-side management, energy efficiency strategies, and policy interventions tailored to residential energy use in cold regions.

HOME APPLIANCES ENERGY CONSUMPTION AND METHODOLOGY

Home appliances

Typical electrical appliances used in the house where five persons reside were used in this study. These appliances were monitored and recorded for the month of December 2023 to determine the device usage schedule and energy consumption data. The details of the residents in the house are given in table 1. The appliances used in this analysis are found typically in homes such as dishwasher, geyser, hair drier, room heater, induction, iron, grinder, kettle, laptop, oven, refrigerator, speakers, television, and washing machine. An energy consumption profile was determined and analyzed for each device considering the device usage schedule and frequency. The details regarding the manufacturer company, model number and energy star rating of the appliances are presented in table 2.

Table 1. Details of residents of the surveyed house

User no.	User Sex	User Age (In Years)
1.	Male	68
2.	Female	63
3.	Male	41
4.	Female	38
5.	Male	19

Table 2. Details of the electrical appliances in home used in the energy consumption profile analysis

S. No.	Appliance	Manufacturer	Model No.	Wattage	Star Rating
1.	Dishwasher	Bosch	SMS46KI03I	2400	★★★★★
2.	Geyser (Washroom)	Marc	Neo Classic–B08HKMJ5TJ	2000	★★★★★
	Geyser (Kitchen)	Crompton	AIWH-3LRPIDJT3KW5Y	3000	★★★★★
3.	Hair Drier	Philips	HP8100/46	1000	
4.	Room Heater	Room 1	Bexco	Unicon - B09R1XK4BS	1500
		Room 2	V-Guard	EQT - 800	800
		Room 3	Bajaj	Minor - B009P2LK08	1000
5.	Induction	Prestige	41992	1200	

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6.	Iron	Bajaj	Majesty DX-8	1000	
7.	Mixer-Grinder	Sansui	Allure	500	
8.	Water Kettle	Milton	Go Electro - CELGELK007ASSR0001	1500	
9.	Laptop	Dell	Inspiron 15R	65	
10.	Oven	LG	MC3286BRUM	2500	
11.	Refrigerator	Whirlpool	IF INV CNV 278	190 KWH/Year	✭✭✭
12.	Television	Samsung	UA32T4340BKXXL	60	✭✭
13.	Washing Machine	LG	P7010RRAZ	410	✭✭✭✭✭

Proposed Methodology

A special energy consumption monitoring device was used to obtain the high-quality energy consumption data of these appliances. The energy monitoring device consists of a smart plug switch with energy meter and monitoring of Edimax company (model no. SP-2101 W – V3) and 16 and 10 Ampere smart plugs for energy monitoring of Wipro company (model no. DSP1160 and DSP1100, respectively). These devices were connected to each appliance manually with Wi-Fi connectivity to determine the energy consumption data. The value of consumed energy of each appliance was monitored by the computer with 11th gen intel core i5 processor, 8Gb of RAM, and 512 GB Intel optane H20 SSD storage device with Windows operating system - V11, with the aim of collecting data from the smart plugs. The data was processed in Microsoft Excel V-2021. Each plug was given with a name of the device that is connected to. The obtained values are formatted to 2 decimal places. The detailed methodology of this study is presented in figure 1.

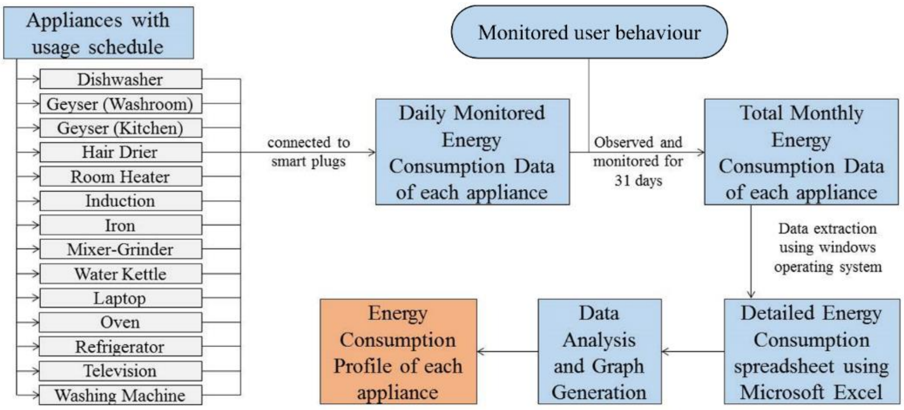

Figure 1. Proposed methodology for data collection

RESULT

In this section, the results of the energy consumption measurements of typical appliances used in home are discussed in detail considering the usage schedule of each appliance used for analysis in this study. The data monitored and recorded for the month of December 2023, when the outside temperature ranges from 4 to 18 °C.

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Dishwasher

A free-standing dishwasher having 6 operating modes was used in the surveyed home. The usage schedule and frequency of usage was monitored, and the total energy consumption was determined. Although there were 6 operating modes in the dishwasher, but it was observed that the economy and intensive washing modes were generally preferred by the user. The monitored frequency of usage of dishwasher in economy mode was twice a week, whereas it was used three times in the respective month in the intensive mode. In the economy mode, the dishes were washed at 50 °C and the time taken by the device in this mode was 3h 30 min. The total energy consumed during the whole program was 960 Wh. The detailed energy consumption profile for a single usage period of dishwasher at economy mode is presented in figure 2. It is seen in figure 2 that the whole program consists of water heating and dishwashing cycles. The total time taken in water heating was 25 min and the energy consumed during this was 853.5 Wh.

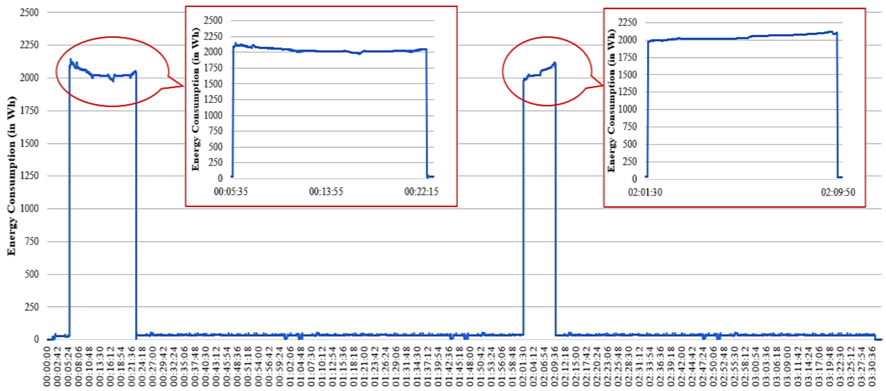

Figure 2. The energy consumption profile for a single usage period of dishwasher in economy mode

Another dishwashing mode used was intensive wash mode, in which the dishes were washed at 70 °C and the time taken by the device in this mode was 58 min. This mode was 4 times shorter than the economy washing mode. The total energy consumed during the whole program was 1093.5 Wh. The detailed energy consumption profile for a single usage period of dishwasher at intensive mode is presented in figure 3. It is seen in figure 3 that the energy consumption in intensive mode is higher than the economy mode, as the water temperature need to be at higher degree in 4 times shorter duration. The total time taken in water heating was 31 min. and the total energy consumed during this was 1062 Wh. As seen in figure 1 to 3, each operation was performed in either water heating mode or standby mode. The total energy consumption during stand by usage is 106.5 Wh in economy mode and 31.5 Wh in intensive mode. Considering the same usage schedule and user behavior, the ratio of energy consumption in heating is 88.9 % in economy mode and 97.1 % in intensive mode.

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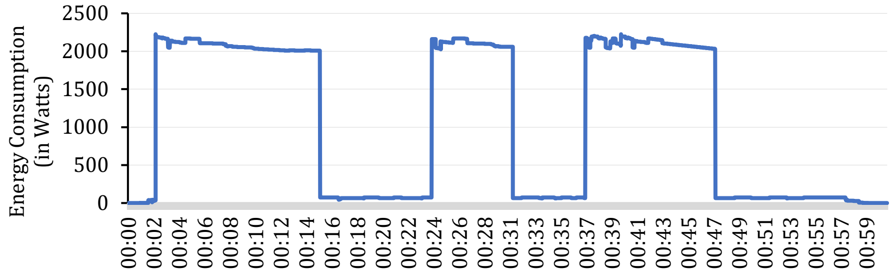

Figure 3. The energy consumption profile for a single usage period of dishwasher in intensive mode

Geyser

Different geysers (3 in no.) were used in the surveyed home, two were used in the washroom and one was used in the kitchen. The geyser was used daily and the frequency and schedule of usage along with the total energy consumption is discussed in the respective sub-parts.

a. Washroom: Two similar geysers were installed in the washrooms, and the different usage schedule was observed for them. Geyser 1 was switched on twice a day, whereas geyser 2 was switched on thrice a day during morning time. The average duration for which these geysers got switched on was 24 and 21 minutes (min.), respectively for geysers 1 and 2. The average energy consumption during each usage duration by geyser 1 was 687.4 Wh and 611.8 Wh by geyser 2. The output temperature of water was set at 75 °C. The total daily usage duration recorded for both the geysers was 1 hour (hr) 54 min., providing the average hourly consumption of 1,696.7 Wh. The detailed energy consumption profile and usage schedule of both the geyser of washroom is presented in figure 4 and table 3.

b. Kitchen: One geyser was installed in the kitchen and switched on thrice a day. The average duration for which it was switched on was 18 min. and the average energy consumption during each time was 811.9 Wh. The output temperature of water was set at 75 °C. The total daily usage duration recorded of this geyser was 54 min., providing the hourly energy consumption of 2,699.8 Wh. The detailed energy consumption profile and usage schedule of this geyser is presented in figure 5 and table 3.

Table 3. Usage schedule of geysers installed in the surveyed home (washroom and kitchen)

Geyser location	Usage schedule	Usage Duration	Energy Consumption (in Wh)	User age
1.	08:12:22 – 08:39:43	26 min 22 sec	1535.75	Female / 63 Years
2.	09:02:27 – 09:24:39	22 min 13 sec	1293.89	Male / 68 Years
	07:04:21 – 07:26:58	22 min 38 sec	1318.66	Male / 41 Years
3.	07:47:37 – 08:03:27	15 min 51 sec	923.15	Female / 38 Years
4.	08:21:53 –	26 min 27 sec	1541.08	Male / 19 Years

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	08:48:19 08:43:22 – 08:59:31 14:03:47 – 14:23:27	16 min 10 sec	673.35	Female / 38 Years
		19 min 41 sec	819.20	Female / 38 Years
5.	21:49:33 – 22:07:49	18 min 17 sec	761.00	Female / 38 Years
6.	08:12:22 – 08:39:43	26 min 22 sec	1535.75	Female / 63 Years
7.	09:02:27 – 09:24:39	22 min 13 sec	1293.89	Male / 68 Years
8.	07:04:21 – 07:26:58	22 min 38 sec	1318.66	Male / 41 Years

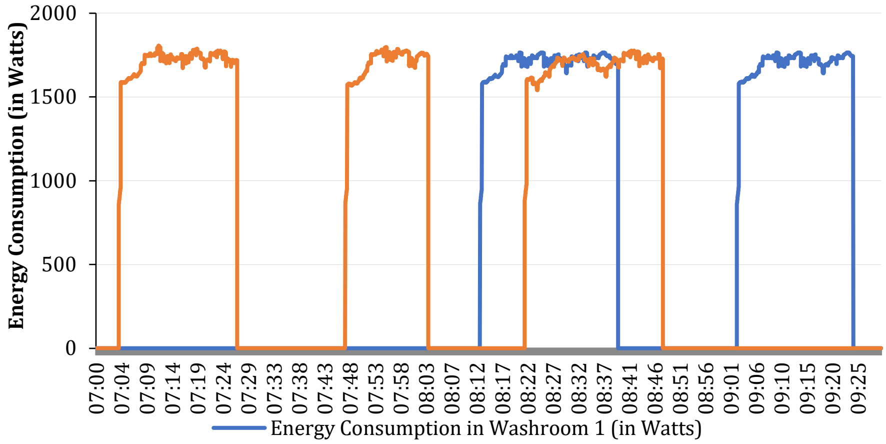

Figure 4. The energy consumption profile of geysers installed in washrooms.

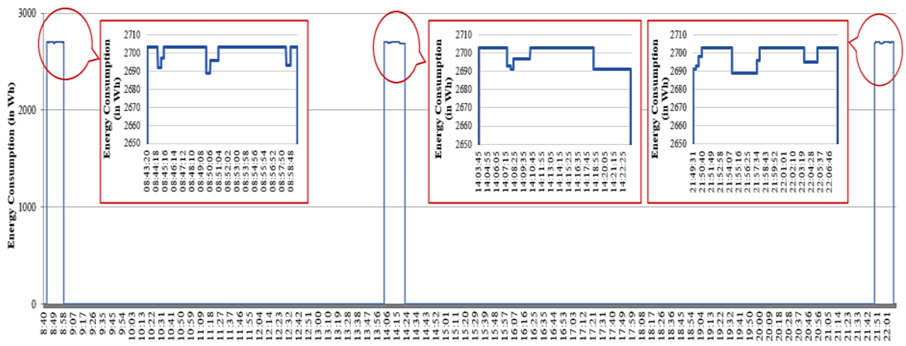

Figure 5. The energy consumption profile of geyser installed in kitchen.

Geyser

A 1000 W power rated hair dryer having two operating modes was used in the surveyed home. The energy consumed was determined and the usage schedule was monitored. It was observed that the dryer was used for nearly 5 min in the high-speed mode and the usage in slow speed mode was negligible, as the dryer comes in this mode while switching on and off, and not for the hair drying purpose. The total energy consumed during this duration was determined as 82.41 Wh. It was used two times a week for nearly the same duration. The weekly total duration of usage of hair dryer was determined to be nearly 11 min., through which the weekly energy consumption of hair dryer was determined as 165 Wh. The energy consumption profile of the hair dryer for a single usage period is presented in figure 6.

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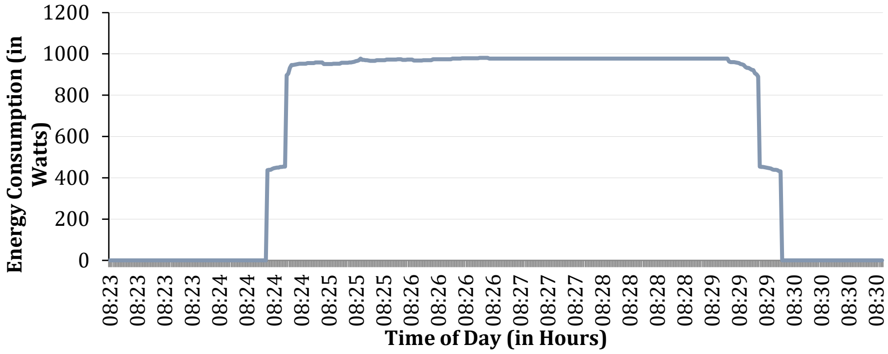

Figure 6. The energy consumption profile of single usage period of hair dryer used in the surveyed home.

Room Heater

Different room heaters (3 in no.) of different wattage were used for space heating in different rooms of the surveyed home. These heaters were used daily, and the frequency and schedule of usage were monitored.

First heater was used in the room of the old age people of the house. It was a radiant heater of 1500 W power rated having double quartz rods. The usage schedule was monitored, and it was observed that the heater in this room was switched on thrice a day for the duration of 1 hr 46 min, 1 hr 3 min, and 3 hr 2 min. The energy consumption during switched on was 2505.2 Wh, 1493.9 Wh, and 4309.78 Wh. The average duration of switched on each time was 1 hr 57 min and the average energy consumption each time was 2,769.6 Wh. The total energy consumption per day and the average hourly consumption of a first heater were determined as 8,308.9 Wh and 1,413 Wh respectively.

Second heater was used in the room of the elder people of the house. It was also a radiant heater of 800 W power rated having double quartz rods. The usage schedule was monitored, and it was observed that the heater in this room was switched on twice a day for the duration of 1 hr 23 min, and 5 hr 16 min. The energy consumption during switched on was 1074.3 Wh, and 4095.8 Wh. The average duration of switched on each time was 3 hr 20 min and the average energy consumption each time was 2,585 Wh. The total energy consumption per day and the average hourly consumption of a second heater were determined as 5,170 Wh and 776.5 Wh respectively.

Third heater was used in the room of the child of the house. It was also a radiant heater of 1,000 W power rated having double ceramic coil rods. The usage schedule was monitored, and it was observed that the heater in this room was switched on thrice a day for the duration of 1 hr 6 min, 21 min, and 4 hr 40 min. The energy consumption during switched on was 1065.6 Wh, 347.75 Wh and 4476.6 Wh. The average duration of switched on each time was 2 hr 2 min and the average energy consumption each time was 1,963.3 Wh. The total energy consumption per day and the average hourly consumption of a third heater were determined as 5,889.9 Wh and 962.4 Wh respectively.

The detailed usage schedule of all the three heaters is presented in table 4 and the energy consumption profile is presented in figure 7.

Table 4. Usage schedule of room heaters used for space heating in the surveyed home.

Heater location	Heater Type and wattage	Usage schedule	Usage Duration	Energy Consumption	Heater location
Room 1	Radiant Heater with double quartz rods (1500 W)	07:37:21 – 09:23:47	1 Hr 46 min 27 sec	3533.8	Female/ 63 Years Male/ 68 Years
		13:19:07 – 14:22:29	1 Hr 3 min 23 sec	2106.2	
		09:02:27 – 09:24:39	3 Hr 2 min 40 sec	6074.4	
Room 2	Radiant Heater with double quartz rods (800 W)	07:17:04 – 08:39:57	1 Hr 22 min 54 sec	1104.8	Female/ 38 Years Male/ 41 Years
		18:41:29 – 23:58:03	5 Hr 16 min 35 sec	4218	
Room 3	Radiant Heater with double ceramic coil rods (1000 W)	06:37:43 – 07:44:09	1 Hr 6 min 27 sec	1106.8	Male/ 19 Years
		08:28:11 – 08:49:51	0 Hr 21 min 41 sec	361.2	
		19:03:18 – 23:42:21	4 Hr 39 min 04 sec	4649.0	

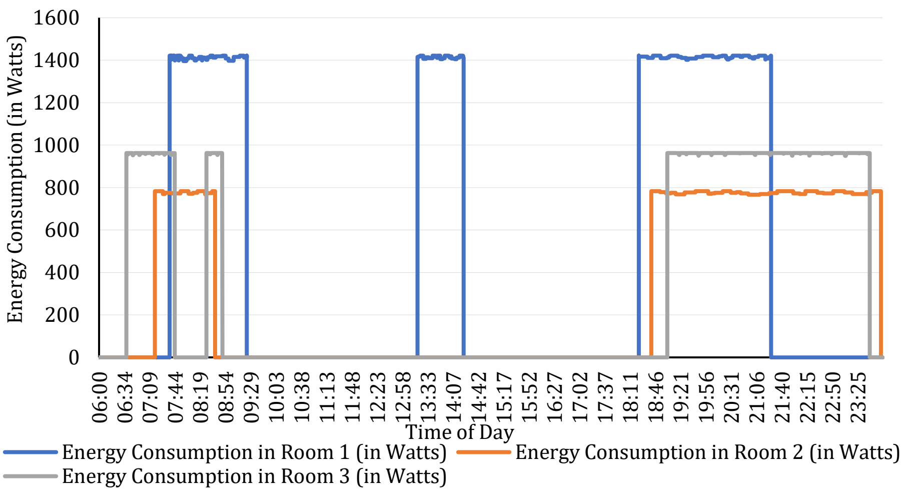

Figure 7. The energy consumption profile of room heaters used for space heating in the surveyed home.

Induction

A 1200 W power rated induction with seven standard operating modes for cooking different eatables was used in the surveyed home. The usage schedule was monitored and the user behavior towards different operating modes was observed. It was noticed that the user preferred to use it in two modes majorly (i.e., mode 5 and 7). The average power rated of mode 5 was 80 W and 1200 W of mode 7. On an average, the device was used twice a day at operating mode 5 for 48 min each time and thrice a day at operating mode 7 for 37 min each time. It was also noticed that even after the induction was switched off, the fan continued to remain on until the device reaches an adequate temperature level. The detailed energy consumption profiles of induction in operating mode 5 and 7 for single usage period are presented in figure 8 and 9, respectively. It is seen in figures 8 and 9 that the induction performs the operation in heating and standby cycles. The total energy consumed during a single usage period of the device was 34.4 Wh at mode 5 and 452 Wh at mode 7. Out of the total energy

DOI10.15320/ICONARP.2025.333

consumption, it was calculated that the heating time in a single usage period was 23 min 9 sec and 24 min 55 sec, in operating mode 5 and 7, respectively, and the energy consumed during this was 23.6 Wh in mode 5 and 444 Wh in mode 7. When the induction was at standby mode, the energy was consumed by the fan. The total energy consumption during stand by usage is 10.8 Wh in mode 5 and 8.0 Wh in mode 7. Considering the same usage schedule and user behavior, the ratio of energy consumption in heating is 68.7% in mode 5 and 98.2% in mode 7.

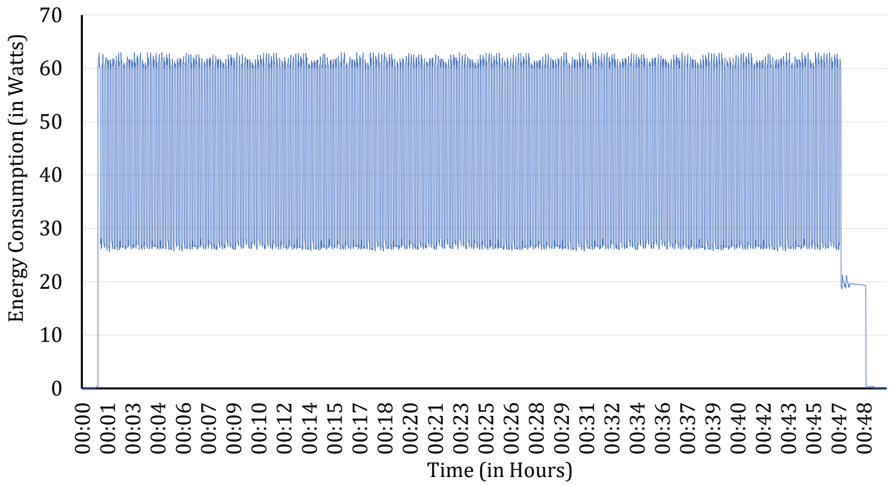

Figure 8. The energy consumption profile of induction for a single usage period at operating mode 5 (i.e., at 80 Watt-hour rated energy consumption)

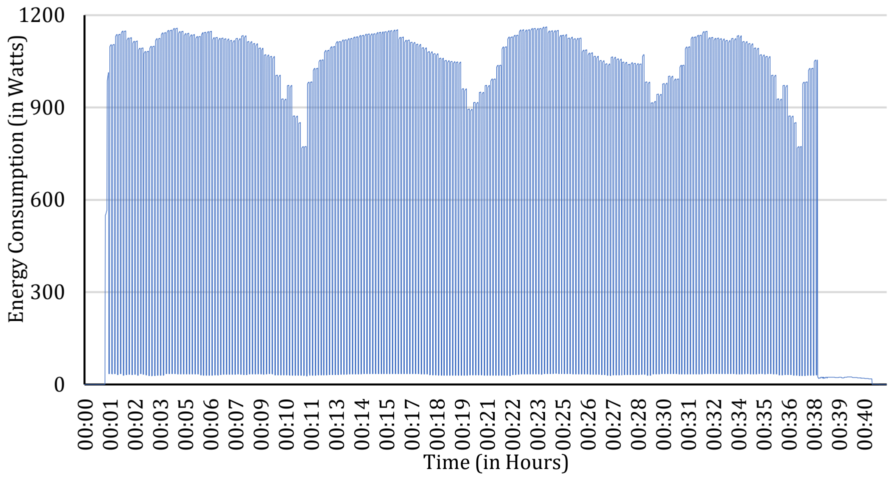

Figure 9. The energy consumption profile of induction for a single usage period at operating mode 7 (i.e., at 1200 Watt-hour rated energy consumption)

Iron

An 800 W power rated iron with three temperature modes for the ironing of different cloths was analysed, and the user generally preferred to use it at temperature mode 2, which was suggested for woollen and silk clothes. It was observed that the iron was used once a week and the average duration for single ironing period was monitored as 1 hr 8 min. The detailed energy consumption profile for single ironing period is presented in figure 10. The heating mode and the standby mode can be observed in figure 10 and the duration for each mode was determined as 29 min and 39 min, respectively. The energy consumed during the heating mode was calculated as 328.15 Wh. It was also observed that during the standby mode of the above-said duration, the iron consumed a negligible amount of energy, i.e., 0.03 Wh, which gives an average weekly energy consumption of iron as 328.18 Wh.

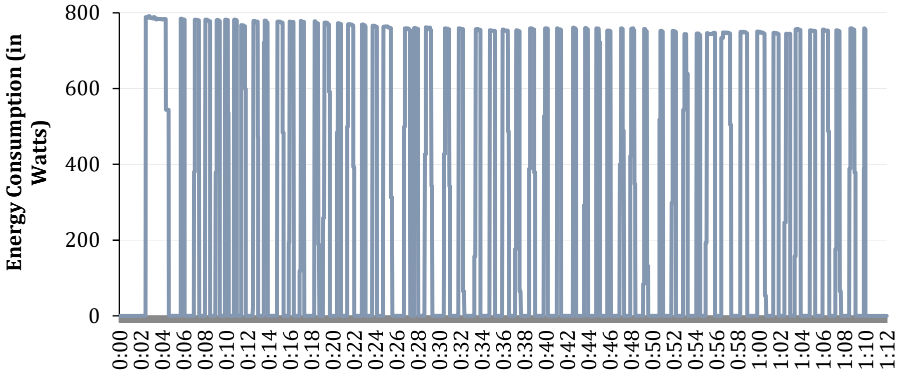

Figure 10. The energy consumption profile of iron for a single usage period at operating mode 2

Mixer-Grinder

A mixer-grinder of 500 W power rated motor having three operating modes was used in the surveyed home. The energy consumption in the mostly used mode was determined and the usage schedule and frequency were monitored. Although, there were three operating modes in the mixer-grinder, but it was observed that the user used it in the first mode only. Also, the mixer-grinder was used once in a day. The average duration of usage was 33 sec and the energy consumed during this duration was calculated as 3.75 Wh. The total duration of usage in a month was determined as approximately 17 min 3 sec. and the total monthly energy consumption was calculated as 116.25 Wh. The detailed energy consumption profile of mixer-grinder for a single usage period in mostly used operating mode (i.e., first mode) is presented in figure 11.

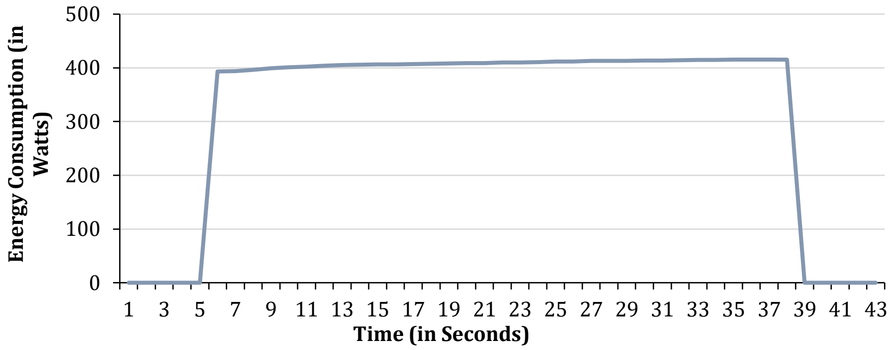

Figure 11. The energy consumption profile of mixer-grinder for a single usage period in first operating mode

Water Kettle

A 1500 W power rated water kettle of 1.5 litres water heating capacity having single operating mode was used in the surveyed home. The energy consumption with different water levels was determined and the usage schedule and frequency were monitored. Inspite of 1.5 litres capacity, it was observed that the kettle was generally used for heating 1 litre of water at a time. The time taken for boiling 0.5,1, and 1.5 litres of water was approximately 4 min 53 sec, 7 min 39 sec and 9 min 11 sec respectively. The energy consumed during this duration was

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120.18 Wh, 189.59 Wh and 228.64 Wh for 0.5,1.0, and 1.5 litres of water, respectively. The detailed energy consumption profile of water kettle with different water levels is presented in figure 12.

(a)

(b)

(c)

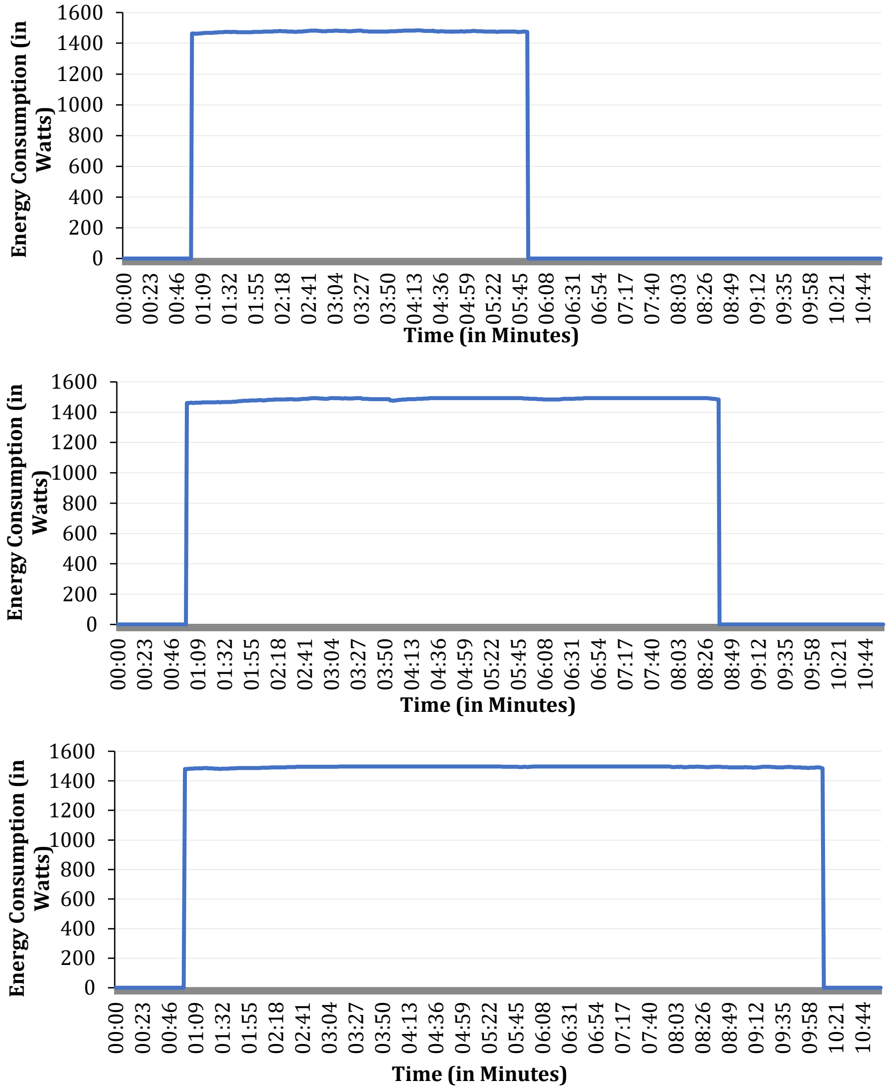

Figure 12. The energy consumption profile of water kettle at different levels (a) 0.5 L, (b) 1 L, and (c) 1.5 L

Laptop

A 15" screen size laptop with 65 W power rated charger was another device which was used frequently in the surveyed home. The usage schedule of laptop was observed, and the energy consumption was determined. The average daily usage duration of laptop was monitored as 3 hr 22 min, out of which 57 min was used while charging and then on the 2-cell lithium-ion inbuilt battery of the laptop. It was observed that as soon as the battery of the laptop was fully charged, the charger was disconnected by the user. The energy consumption during this duration was determined as 57.95 Wh. The laptop was used daily and in the evening time only. According to this assumption that the user behavior towards switching-off the charger does not change, the monthly energy consumption of laptop was calculated as 1796.45 Wh.

The detailed energy consumption profile of laptop during a single charging period is presented in figure 13.

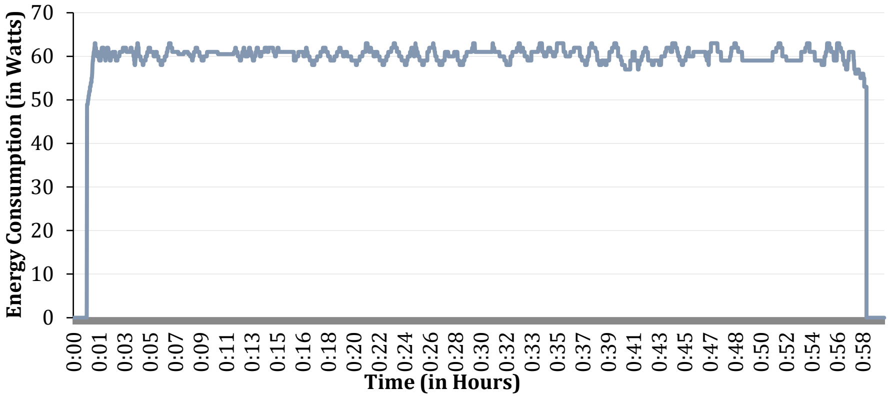

Figure 13. The energy consumption profile of laptop for a single charging period

Oven

Oven was another appliance that was considered in this study, as it plays a significant role in the overall energy consumption in the surveyed home. The usage schedule was monitored, and the energy consumption was determined. It was observed that the oven was used twice a day at 120 °C, thrice a week at 150 °C, and twice a week at 180 °C. It was also noted that even after the oven was switched off as per timer, the fan continued to remain on until the device reaches an adequate temperature level. The average duration for which oven was used was 1 min at 120 °C, 8 min at 150 °C, and 53 min at 180 °C. The detailed energy consumption profiles of oven for a single usage period at 180 °C is presented in figure 14. It is seen in the figure 14 that the oven performs the operation in heating and standby cycles. It was observed that when the oven was at standby mode, the energy was consumed by bulb and fan of the oven. The total energy consumed during the single usage period at 120 °C was 29.3 Wh. Out of this, the heating time was determined as 47 sec and the energy consumed during this was 28.6 Wh. The fan remains on till 31 sec after the timer switched off the device. The ratio of heating in a single usage was determined as 97%. Similarly, the total energy consumed during the single usage period at 150 °C and 180 °C was 159.6 Wh and 907 Wh, respectively. Out of this, the heating time was determined as 4 min 32 sec and 22 min at 150 °C and 180 °C, respectively, and the energy consumed during this was 150 Wh at 150 °C and 790 Wh at 180 °C, respectively. The fan remains on till 4 min 19 sec at 150 °C and 15 min 51 sec at 180 °C, after the timer switched off the device. The total energy consumption during stand by usage is 1.3 Wh while using at 120 °C, 9.6 Wh while using at 150 °C, and 117 Wh while using at 180 °C. The ratio of heating in a single usage period was determined as 93 % at 150 °C and 87 % at 180 °C.

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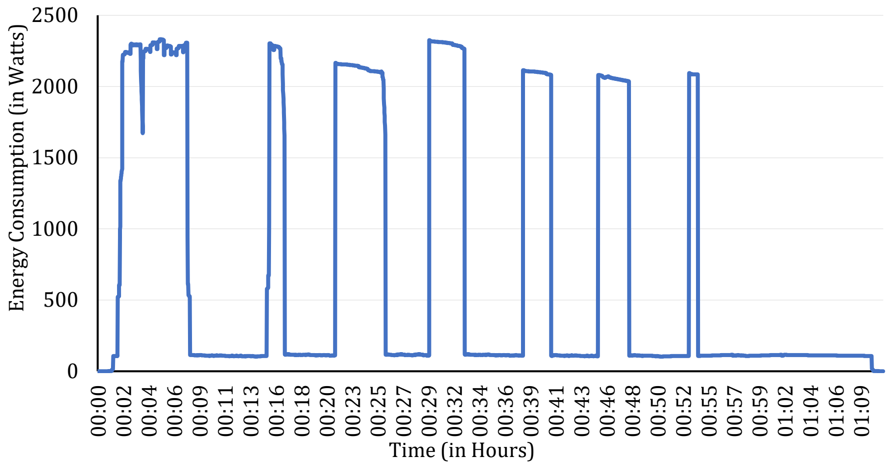

Figure 14. The energy consumption profile of oven for a single usage period at 180 °C

Refrigerator

A frost-free refrigerator of 265 litres capacity was used in the surveyed home which was switched on for the whole day and night and its daily energy consumption is presented in detail in figure 15. There were cooling cycles of refrigerator at certain intervals of the day and the total cooling time for the day was monitored as 13 hr 4 min. The energy consumption during this cooling process was determined as 62.04 Wh. The door of refrigerator was opened 23 times in the whole day and the average door opening duration was measured as 15 sec. The cooling control was kept at the maximum level. As it is a frost-free refrigerator, it defrosts automatically when required. The same can be observed in the detailed energy consumption profile presented in figure 15 that it performs defrosting twice a day for approximately 18 min each time and the energy consumption during the defrosting process was determined as 276 Wh. The hourly and daily average energy consumption by the refrigerator was determined as 40.74 Wh and 977.87 Wh, respectively. The energy consumption data during the door opening duration of refrigerator was also determined and the change in energy consumption was observed during this. To determine the exact change in energy consumption during this process, the door opening during the standby time of refrigerator was considered. The detailed energy consumption profile during this process is presented in figure 16. The door was opened for 32 sec and 12 sec on the first and second opening respectively and the average energy consumption during this process was determined as 6.74 Wh for the first time and 6.14 Wh for the second time. The door of refrigerator was opened 25 times in the whole day and the average door opening duration was measured as 19 sec. in the surveyed home. Due to the door opening process in the whole day, the refrigerator consumed 0.34 W of energy during each time, which corresponds to 8.5 Wh of daily energy consumption.

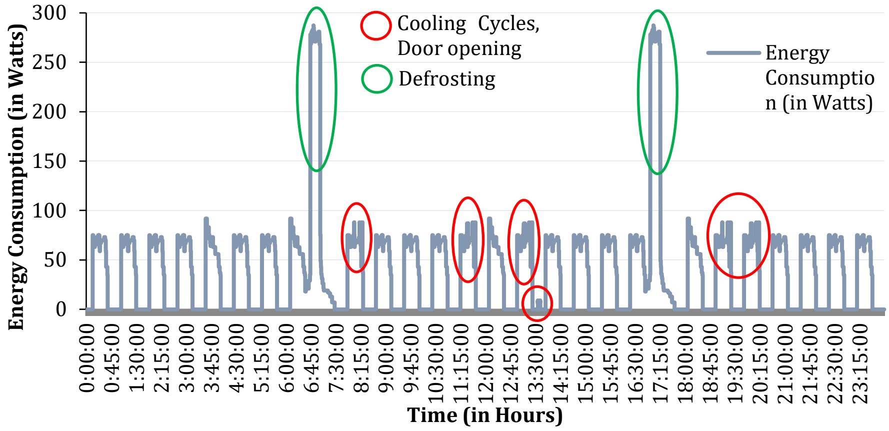

Figure 15. The energy consumption profile of refrigerator used in the surveyed home.

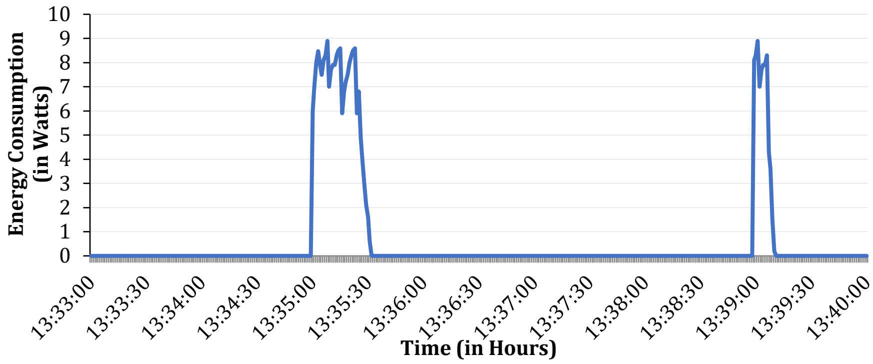

Figure 16. The energy consumption profile of refrigerator during the door opening

Television

A 32" screen size television was another device which was used frequently in the surveyed home. The usage schedule of television was observed, and the energy consumption was determined. It was observed that the usage of the device was different for weekdays and weekends. The daily average usage of television during weekdays and weekends was determined as 4 hr 29 min and 9 hr 30 min, respectively. The detailed energy consumption profiles of television for a respective weekday and weekend are presented in figure 17 and 18. The average daily energy consumption of television during weekdays and weekend was calculated as 182.6 Wh and 362.3 Wh, respectively. The hourly average energy consumption of watching period of television was calculated as 40.6 Wh. It was observed that changing the channels also affects the energy consumption of the television. Also, the negligible amount of energy was consumed by television while it was switched off from the remote control only.

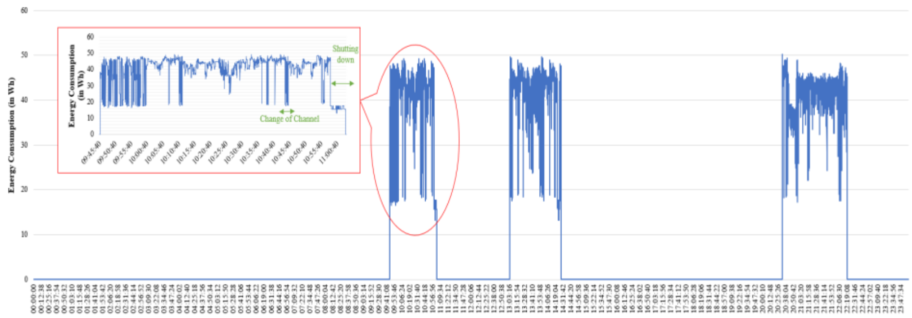

Figure 17. The energy consumption profile of television for a respective weekday

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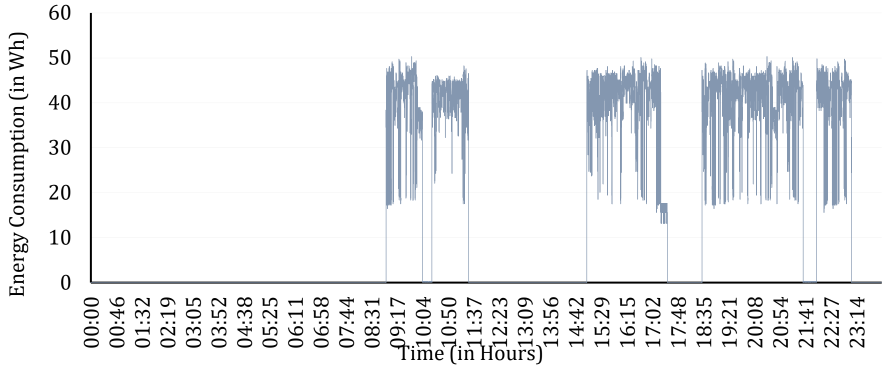

Figure 18. The energy consumption profile of television for a respective weekend

Washing Machine

A top load washing machine having 7 Kg load capacity was used in the surveyed home. The energy consumption of the device was monitored, and the usage schedule and user behavior were observed. The device has 3 washing modes (i.e., gentle, normal, and strong mode) for different types of clothes and was used 4 times a week. To develop the energy consumption profile, the energy consumption was monitored in a way that each time the device was used in a week, it was used in a different washing mode. For example, for the first time, the device was used in the gentle wash mode. Similarly, for the second and third time, the device was used in the normal and strong washing mode. The detailed energy consumption profiles of strong washing mode for a single washing period of 15 min are presented in figure 19. It was observed while analysing the recorded data that each washing period of 15 minutes is comprised of washing and standby cycles for 5 min 2 sec and 9 min 58 sec, respectively in gentle wash mode, 8 min 37 sec and 6 min 23 sec, respectively in normal wash mode, and 12 min 30 sec and 2 min 30 sec, respectively in strong wash mode. The energy consumption by the washing machine in single washing period of 15 min was calculated as 39.96 Wh in gentle mode, 60.4 Wh in normal mode, and 82.4 Wh in strong mode. The ratio of wash time in a single wash cycle was 33.5% in gentle mode, 57.4% in normal mode, and 83.3% in strong washing mode. The spin mode was used for drying the clothes and the average usage duration of spin was 5 min. The energy consumption by the washing machine in spinning mode was calculated as 29.9 Wh and the energy consumption profile of washing machine for a single spin cycle of 5 minutes is presented in figure 20. It was observed that the user always used it in the strong washing mode with water of normal room temperature. The gentle and normal modes were used just for developing the energy consumption profile of the device. Also, it was observed that as per user satisfaction of the washed clothes, 12, 7, and 3 numbers of washing periods were required for each gentle, normal and strong washing mode, respectively. Hence, the total washing period including spin cycle was calculated as 3 hr 5 min, 1 hr 50 min, and 50 min in gentle, normal, and strong washing mode, respectively. The total energy consumed by washing machine was calculated as 509.4 Wh when used in gentle wash mode, 452.7 Wh when used in normal wash mode, and 277.1 Wh when used in strong wash mode, out of which 319.2 Wh in gentle mode, 179.9 Wh in normal mode, and 41.4 Wh in strong mode is consumed in standby mode.

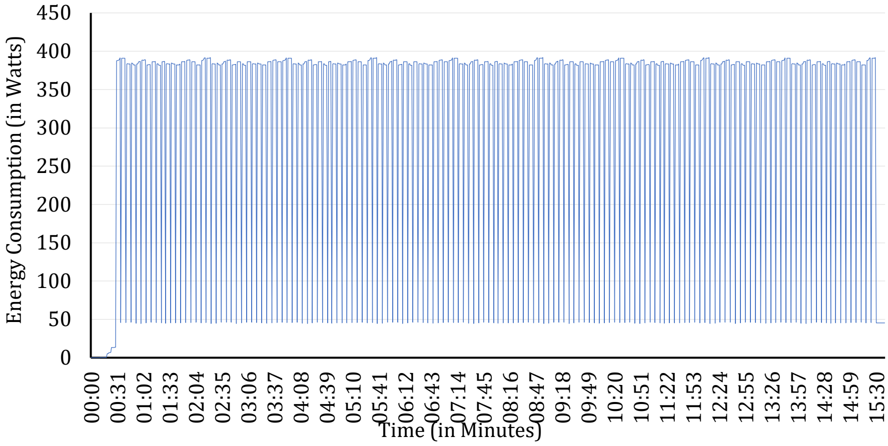

Figure 19. The energy consumption profile of washing machine for a single wash cycle of 15 minutes in strong wash mode

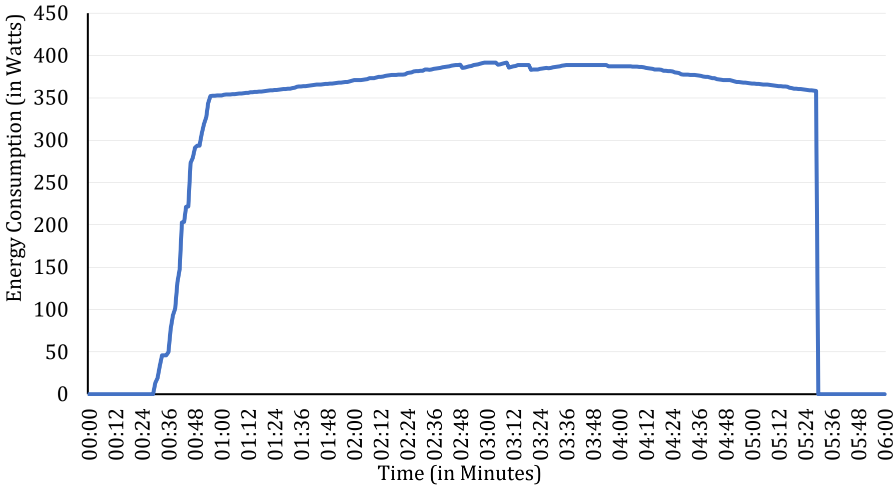

Figure 20. The energy consumption profile of washing machine for a single spin cycle of 5 minutes

DISCUSSION

The detailed appliance-level monitoring conducted in this study provides fresh insights into residential energy consumption in the cold climate of Shimla, Himachal Pradesh. While the results confirmed expected patterns, such as the dominance of room heating and water heating, the discussion requires broader contextualization within the literature, along with an analysis of how climatic conditions, household size, and user behavior shape energy demand. The energy consumption of typical appliances was recorded at one-second intervals, with usage schedules and frequencies monitored on a daily, weekly, and monthly basis. Based on this data, the consumption ratios of different appliances were determined considering user behavior and operating frequency and presented in table 5. The total monthly energy consumption derived from these profiles was further validated against the electricity bill provided by the state electricity board, confirming the accuracy of the measurements.

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Table 5. Usage frequency and total monthly energy consumption of typical household appliances for the month of December 2023

Appliance	Operating Mode	Average Usage Duration		Single Usage Energy Consumption (in Wh)	Usage Frequency	Total Monthly Energy Consumption (in Wh)	Remarks		% of energy wasted due to Stand by mode
Dishwasher	50°C Economy	3 hr 30 min		960	9 per month	11,920.5	Heating energy consumption ratio	88.9 %	11.1%
	70°C Intensive	58 min		1093.5	3 per month			97.1 %	2.9%
Geyser (Washroom)	75°C	Geyser 1	24 min	687.4	2 per day	99,516.2	-	-	-
		Geyser 2	21 min	611.8	3 per day				
Geyser (Kitchen)	75°C	18 min		811.9	3 per day	75,506.7	-	-	-
Hair Drier	High speed	5 min 30 sec		82.41	2 per week	741.7	-	-	-
Room Heater	With both rods	Heater 1	1 hr 57 min	2769.6	3 per day	6,00,429.7	-	-	-
		Heater 2	3 hr 20 min	2585	2 per day				
		Heater 3	2 hr 2 min	1963.3	3 per day				
Induction	Mode 5	48 min		34.4	2 per day	44,168.8	Heating energy consumption ratio	68.7 %	31.3%
	Mode 7	37 min		452	3 per day			98.2 %	1.8%
Iron	Mode 2	1 hr 8 min		328.18	1 per week	1,640.9	Heating time ratio	74.3 %	25.7%
Mixer-Grinder	Mode 1	33 sec		3.75	1 per day	116.25	-	-	-
Water Kettle	0.5 L	4 min 53 sec		120.18	4 per week	15,061.02	-	-	-
	1.0 L	7 min 39 sec		189.59	2 per day				
	1.5 L	9 min 11 sec		228.64	1 per week				
Laptop	On charging	57 min		57.95	1 per day	1,796.5	-	-	-
Oven	120 °C	1 min		29.3	2 per day	12,054.4	Heating resistor ratio	97%	3%
	150 °C	8 min		159.6	3 per week			93%	7%
	180 °C	53 min		907	2 per			87%	13%

				week				
Refrigerator	Level 7	24 hours	977.87	24 hours	30,313.97	Defrosting energy consumption ratio	14.2 %	-
Television	Weekday	4 hr 29 min	182.6	22 per month	7,277.9	-	-	-
	Weekend	9 hr 30 min	362.3	9 per month				
Washing Machine	Gentle (12 turns)	Each cycle is of 15 min	39.96 W in each cycle	1 per month	5,395.7	Spin cycle is of 5 min and consumes 29.9 W in each usage. Total energy consumption includes spin.	-	66.5%
	Normal (7 turns)		60.4 W in each cycle	1 per month				42.6%
	Strong (3 turns)		82.4 W in each cycle	16 per month				16.7%

As it is already mentioned that the energy consumption data of these appliances were recorded in the interval of one second and the usage frequency was monitored. The average energy consumption data in a single usage period was calculated. The monthly energy consumption of each appliance was determined using equation 1.

$$\textbf{\textit{Monthly energy consumption}}\ (\textbf{\textit{in KiloWatt Hour}}) =$$

$$\frac{(Average\ usage\ duration * single\ usage\ energy\ consumption * usage\ frequency}{1000}$$ **Equation 1**

The same usage duration, single usage energy consumption was considered, and the user behavior, & the usage frequency of each device was monitored in the month of January 2024, and the energy consumption has been determined and presented in table 6. The obtained value of total monthly energy consumption was later validated with the monthly energy consumption bill monitored by the state electricity board.

Table 6. Usage frequency and total monthly energy consumption of typical household appliances for the month of January 2024

Appliance	Operating Mode	Single Usage Energy Consumption (in Wh)	Usage Frequency	Total Monthly Energy Consumption (in Wh)
Dishwasher	50°C Economy	960	11 per month	13,840.5
	70°C Intensive	1093.5	3 per month	
Geyser (Washroom)	75°C	687.4	2 per day	99,516.2
		611.8	3 per day	
Geyser (Kitchen)	75°C	811.9	3 per day	75,506.7
Hair Drier	High speed	82.41	11 per month	906.51

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Room Heater	With both rods	2769.6	3 per day	6,00,429.7
		2585	2 per day	
		1963.3	3 per day	
Induction	Mode 5	34.4	2 per day	44,168.8
	Mode 7	452	3 per day	
Iron	Mode 2	328.18	6 per month	1,969.08
Mixer-Grinder	Mode 1	3.75	27 per month	101.25
Water Kettle	1.0 L	189.59	94 per month	17,821.46
Laptop	On charging	57.95	22 per month	1,274.9
Oven	120 °C	29.3	71 per month	8,051.7
	150 °C	159.6	9 per month	
	180 °C	907	5 per month	
Refrigerator	Level 7	977.87	24 hours	30,313.97
Television	Weekday	182.6	22 per month	7,277.9
	Weekend	362.3	9 per month	
Washing Machine	Strong (3 turns)	82.4 W in each cycle	21 per month	5,221.1

The total energy consumption of the appliances used in this study was calculated as 905.9 kWh for the month of December 2023 and 909.4 kWh for the month of January 2024. This value was then validated by the energy consumption bill monitored by the state electricity board and the actual energy consumption of the surveyed home for December 2023 was 933 kWh and January 2024 was 958 kWh. The difference of 27 kWh and 48.6 kWh in the actual and measured energy consumption values for the month of December and January, respectively, represents the energy consumed by the rest appliances such as lighting, mobile charging, ceiling fans (used after room cleaning), speakers, exhaust fans (washroom and kitchen), which were excluded from the study. This validated the accuracy of the measured data and the data monitoring methodology. It is to be noted that the difference in actual and measured energy consumption values for the month of January 2024 is higher, which occurs due to the change in actual and assumed usage duration of each device. The total energy consumption of various appliances and their energy consumption ratios for December 2023 and January 2024 are presented in table 7 and figure 21.

Table 7. The total energy consumption of various appliances and their energy consumption ratios for December 2023

S. No.	Appliance	Energy Consumption (in Wh)		Energy Consumption Ratio	
		December 2023	January 2024	December 2023	January 2024
1	Dishwasher	11,920.5	13,840.5	1.28 %	1.45%
2	Geyser (Washroom)	99,516.2	99,516.2	10.67 %	10.42%
3	Geyser (Kitchen)	75,506.7	75,506.7	8.09 %	7.91%
4	Hair Dryer	741.7	906.51	0.08 %	0.09%
5	Room Heater	6,00,429.7	6,00,429.7	64.35 %	62.87%

6	Induction	44,168.8	44,168.8	4.73 %	4.63%
7	Iron	1,640.9	1,969.08	0.18 %	0.21%
8	Mixer-Grinder	116.25	101.25	0.01 %	0.01%
9	Water Kettle	15,051.5	17,821.46	1.61 %	1.87%
10	Laptop	1,796.5	1,274.9	0.19 %	0.13%
11	Oven	12,054.4	8,051.7	1.29 %	0.84%
12	Refrigerator	30,313.97	30,313.97	3.25 %	3.17%
13	Television	7,277.9	7,277.9	0.78 %	0.76%
14	Washing Machine	5,395.7	5,221.1	0.58 %	0.55%
15	Others	27,069.98	48600.23	2.9 %	5.09%

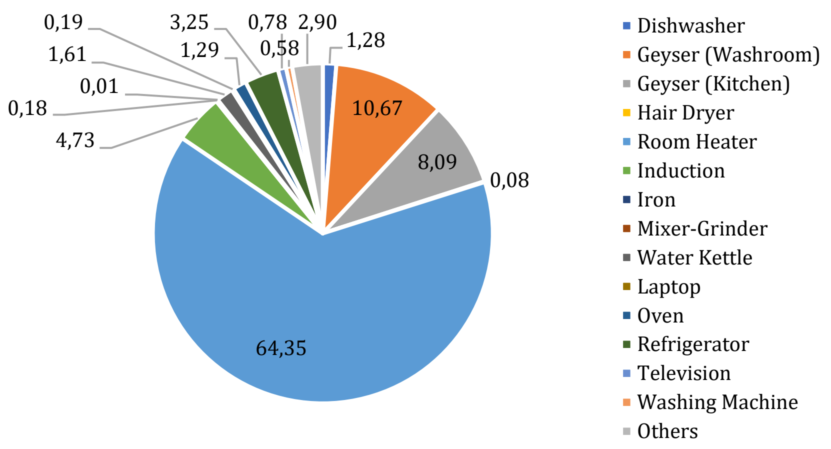

Figure 21. The energy consumption ratios (in %) of different appliances for December 2023

It is seen in table 7 and figure 21 that the room heaters and geysers accounted for the highest share of household electricity consumption during December (i.e., 83.11 %). This outcome is consistent with research on households in cold-climate regions, which report that space heating and water heating dominate residential electricity demand during winter (International Energy Agency, 2017; Nainwal & Sharma, 2024). However, the proportion of electricity devoted to heating in this study was higher than that reported in metropolitan or composite climate regions, where cooking, cooling, and lighting loads form larger shares of consumption (Maurya et al., 2023). This distinction underscores how Shimla's climatic context, marked by extreme low temperatures and reliance on electric appliances due to the absence of centralized heating systems, shapes appliance uses differently from other parts of India and the world. These findings suggest that energy-efficiency policies for hilly regions must emphasize thermal insulation and efficient heating systems rather than focusing solely on cooling technologies, as often seen in national-level policy frameworks.

Beyond climate, user behavior significantly affected the energy consumption profiles observed. For example, the intermittent cooking patterns on the induction cooktop, the choice to keep refrigerators continuously running, and standby consumption from devices such as the microwave oven fan and induction system cooling added hidden but measurable loads. Previous studies on standby power consumption

DOI10.15320/ICONARP.2025.333

confirm that while individual standby loads are small, they cumulatively account for a substantial proportion of household electricity demand (Boegle et al., 2010; Meier, 2001). Similarly, the presence of a five-member family in this study amplified overall appliance usage compared to smaller nuclear families, a finding also observed by (Ekholm et al., 2010), who reported household size as a significant predictor of residential energy intensity in Indian contexts. These results highlight the need for considering demographic and behavioural factors when designing appliance-level interventions.

Previous work in composite and warm-humid climates (Maurya et al., 2023) shows seasonal shifts in demand, where cooling and ventilation dominate in summer, whereas in Shimla's mild summers, demand is restricted mainly to lighting and small appliances. This seasonal variation suggests that the annual energy profile of Shimla households would look drastically different from the winter-dominated profile captured here. Future work should therefore extend monitoring across multiple seasons to develop a more representative year-round dataset.

The appliance-level profiles generated in this study have direct implications for both households and utilities. At the household level, they highlight opportunities for reducing consumption, such as replacing conventional geysers with solar water heaters or heat pump-based systems and minimizing reliance on inefficient electric room heaters through better building insulation. These strategies align with recommendations from the Bureau of Energy Efficiency (Efficiency, 2020) on household efficiency improvements. At the utility level, the data provides a basis for more accurate demand-side management. By anticipating winter peak loads in hilly regions, utilities can design time-of-use tariffs, promote efficient appliances, and integrate smart metering strategies. These applications resonate with global literature, which shows that detailed monitoring of household appliances enables utilities to manage peak demand and promote energy savings (Hong et al., 2020; International Energy Agency, 2017; Xu et al., 2020).

CONCLUSIONS AND RECOMMENDATIONS

This study determines the actual energy consumption profiles of typical home appliances in one second interval. A wireless smart plug was used for monitoring energy consumption and a computer with the specific requirements was used for data extraction and graph generation. The energy consumption data of various household appliances typically used in home with a family size of 5 people was monitored along with their usage schedule and frequency for one month. By analysing the monitored data, the duration and energy consumption by usage and standby cycles along with the overall energy consumption ratios of these appliances were calculated in detail. The following can be concluded:

- Although, the energy consumption units for each month will vary with the variation in usage schedule of appliances, number of persons living, and occupancy schedule of the house, but the ratio of energy consumption during operation and standby mode of appliances at different operating modes, as determined & presented in table 5 of this study, will remain same. Further, using these ratios, per-hour energy consumption value, and by monitoring the usage schedule for each appliance, the hourly, daily, as well as monthly energy consumption can be determined, as shown in this study.
- The amount of energy being wasted in different operating modes of an appliance in a single operation cycle has been determined in this study. The wastage is due to the user-behavior of keeping the device into standby mode. Therefore, the findings of the study also provide an idea of the amount of energy wastage because of user behavior of keeping the device into standby mode. Thus, this waste can be reduced by altering the user behavior.
- It has been observed that the higher/stronger the operating mode of the appliance is, the better is the energy consumption ratio and less is the energy wasted in standby mode of the appliance.
- The percentage share of energy consumption by each device determined in this study can be useful for the energy distribution companies in predicting the energy demand in the respective geographical area.
- Similar research on gas and water consumption can be conducted. Also, the scope of research can be extended to the non-residential buildings and different climatic zones.

Accordingly, the appropriate measures for reducing the energy wastage and energy bill can be taken and energy efficiency can be enhanced. Also, the energy consumption profiles developed in this study will be useful for the researchers working on Smart Grids and Energy Prediction Models as it provides the data at one-second interval.

ACKNOWLEDGEMENTS/NOTES

No funding has been received for this work.

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Resume

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DOI10.15320/ICONARP.2025.333