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Residential Energy Conservation using Efficient Home Appliances

Md. Abdullah Ansari, Arshad Mohammad, Mohd Tariq, Ahmed Riyaz

Abstract: ***Significant hike in global energy demand has laid extra pressure on energy generation plants and natural environment as well. Therefore, methods of reducing the global energy demand are being extensively explored worldwide. In this paper, we have discussed ways of reducing energy consumption in Residential sector. We have taken eight major appliances being used in homes and compared them on the basis of annual energy consumed and cost saving by taking suitable assumptions like running hours, seasons of operation, etc. Finally, Case study of a modern house in Aligarh district of UP is studied for analysing the percentage consumption of each appliance being discussed. The results show that appliances like light bulbs, ceiling fans and refrigerators have the highest potential of energy as well as cost saving by improving their efficiency. Further, by switching all the appliances from conventional to the most efficient models resulted in energy and cost saving of about 37% in the house taken for case study.***

Keywords: ***Energy Consumption, Cost Saving, Efficient Appliances, Residential Electricity Consumption (REC).***

I. INTRODUCTION

Globally, energy demand is increasing at a very fast pace. This rapid and continuous increase possesses several problems such as shortage of energy supply, environmental degradation and excessive consumption of fossil fuels to name some of them[1]. Among, all the problems arising out of the dearth of energy, Environmental degradation is of the most concern presently, which includes global warming, ozone layer depletion, etc.[2]. In India, Primary Energy

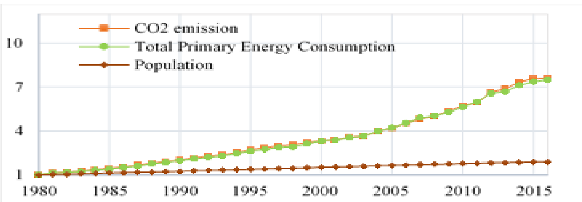

Figure 1. Primary energy consumption, CO2 emission and Population of India (1980-2016)

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***** Correspondence Author

Md Abdullah Ansari*, Electrical Engg. Dept., ZHCET, AMU, Aligarh. Email: maansari11@myamu.ac.in

Arshad Mohammad, Electrical Engg. Dept, ZHCET, AMU, Aligarh. Email: arshad.gb2140@gmail.com

Mohd Tariq, Electrical Engg. Dept, ZHCET, AMU, Aligarh. Email: tariq.ee@zhcet.ac.in

Ahmed Riyaz, Department of Electrical Engg. , BGSB, J&K. Email: ahmedriyaz@bgsbu.ac.in

Consumption and CO_2 emissions have increased severely (over 7 times) in the last two decades (1980-2016) (fig. 1)[3]. Rise in demand is more as compared to generation which has led to base energy and peak energy shortages of 0.7% and 2% respectively in the year 2018(fig. 2 and 3)[4]. In order to meet energy demand, more power generation

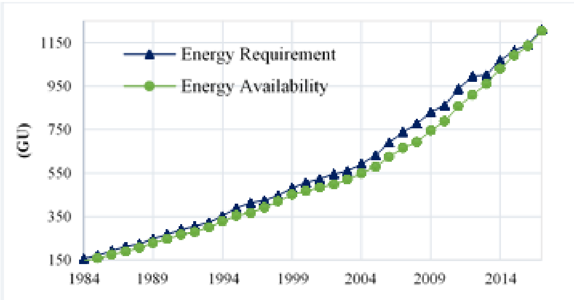

Figure 2. Base Energy requirement and availability (GU) In India (1984-2017)

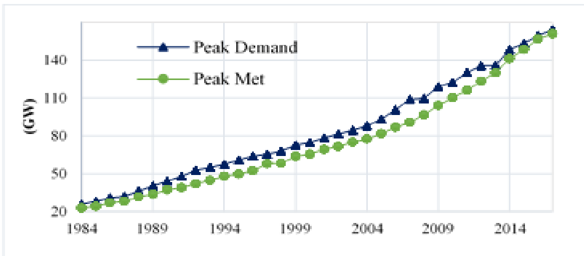

Figure 3. Peak Energy Demand and Met (GW) in India(1984-2017)

plants are required. Conventionally, anticipating the future energy demands, government decided to come up with additional power plants. However, increment of power plant capacity incessantly is becoming highly unsustainable[5]. Setting new plant requires large area which leads to confrontation from the locals as it harms the prospects of local people and natural environment as well. Burning of fossil fuels for operating power plants produces greenhouse gases which cause global warming. Also, presence of limited amount of fossil fuels restrain setting additional generation units. Although, non-conventional sources like solar, wind and tidal energy are free from these constraints, they are not feasible because of their sporadic behaviour[6]. However, another way of balancing supply and demand is by reducing the consumption of electricity[7]. One way of doing this is by using efficient appliances in homes, because of the fact that residential sector contributes for about 20-40% of overall electricity consumption in India (Fig. 4)[8].

The year-wise growth of Residential Electricity Consumption (REC) in India is shown in Fig. 5[9].

It is anticipated to escalate further in coming future due to growth of population, change in human lifestyle, advancement of technology, etc. [10]. So, a broad analysis of major factors affecting the REC is essential for forecasting the accurate future demand which will come in handy for the optimised planning of additional generation capacity. Secondly, since energy sector contributes for about 63% of all greenhouse gas

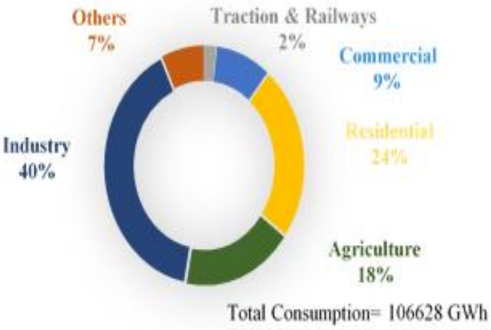

Figure 4. Sector-wise Consumption of Electricity in India during 2016-17

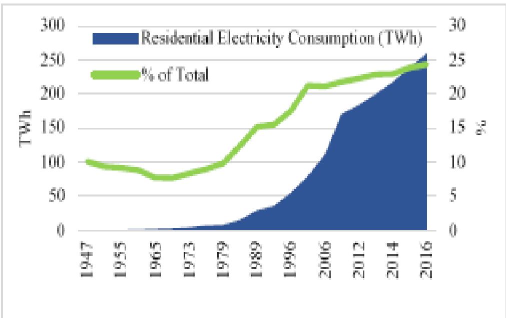

Figure 5. Residential Electricity Consumption in India (1947-2016)

emissions in India [11], better conservative measures for mitigating these emissions could be taken after understanding the future demand. Lastly, nearly decades ago, addition of renewable power generation technologies like solar, wind, biomass, geothermal and tidal energy are affecting the reliability of the whole power grid[12]. Consequently, Load management is gaining popularity especially in regions where load demand is higher than energy supply. So, the knowledge of electricity consumption pattern is very crucial in optimising load management.

In homes, electricity is used for lighting rooms, space air conditioning (cooling and heating), water heating, refrigeration and many other household purposes. A sound understanding of contribution of ress in total REC is helpful for designing efficient appliances according to their priority of consumption. Many researchers are working on exploring ways of enhancing efficiency of appliances. [13] discussed potential of efficiency enhancement of ceiling fans which would help in reducing total electricity consumption as well as global GHG emissions. [14] reported specific electricity consumption of manual defrost and auto defrost domestic refrigerators. And suggested chief technical areas of improvement like working fluid, insulating medium and increased efficiency in control strategies of thermostat. [15] analysed reduction in total electricity consumption in replacing halogen bulbs with same number of Light Emitting Diode (LED) bulbs. Electricity consumed by lighting reduced from 30% to 10% by replacing 22 halogen bulbs with the same number of LED bulbs. Since, apparent power consumed by appliances consists of both active and reactive components. [16] showed the presence of non-zero reactive component in Inverter type Air Conditioners using virtual instrument platform (NI LabVIEWTM) under IEEE standards and definitions of measurement. Energy saving in shifting to the most efficient appliances could also result in reduction of additional capacity requirement in the future [17]. Results of electricity consumption comparison between Polish homes and selected European Union countries were presented in [18]. At the end, various methods for maximising the energy efficiency in household sector were also suggested. REC is affected by appliances being used like lighting bulbs, AC, refrigerators, etc.[19] whose usage is dependent on physical conditions like climate and geographical location[20]. Renewable energy sources like solar energy is becoming feasible for practical power generation[21]. But power utilization is constrained by its intermittent nature which necessitates the proper analysis of daily load profile of residential, commercial as well as industrial loads [22]. Field measurements of end-use as done by [23] and [24] is very helpful in exploiting the possibilities of Demand Side Management in residential loads. [25] surveyed 400 residential and 200 commercial buildings among three types of income groups in Gujarat. Load curve (fig. 6) is obtained for summer and winter seasons. Peak formed during night and afternoon in summers is mostly due to space cooling appliances like ACs. In winters also, peak occurs during morning which is mostly due to water heating appliances like water heaters.

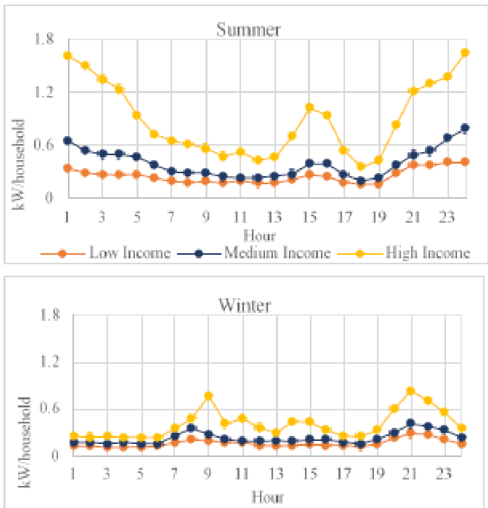

Figure 6. Income based Load Curve of residents in summer and winter

This paper is organized in the following format:

Section 2 deals with comparison of energy consumption and cost saving of eight home appliances namely: Lighting load, Ceiling fan, Refrigerator, AC, Water heater, Washing machine, TV and Microwave oven. Section 3 applies the above appliances in case study of a modern house in Aligarh, district of UP. Results are discussed in section 4. Finally, conclusions of the study is given in section 5.

II. APPLIANCES UNDER STUDY

In this study, we have compared energy consumption and corresponding cost saving of eight major home appliances being used in homes. Conventional as well BEE star rated appliances are included with their latest energy consumption data collected from [26]. The cost of electricity is taken ₹ 6.5 per unit. Finally, we have taken a case study of a modern house in Aligarh district of UP, India. And compared both the above mentioned parameters by taking least and most energy efficient appliances. Each home appliance is described in the subsequent paragraphs:

A. Lighting load

Lighting load constitutes the major part of energy consumption. Incandescent, CFL & LED are the prominent technologies used for lighting homes. Incandescent bulbs came into picture when Sir Humphry Davy discovered incandescence in a platinum wire in 1802[27]. Presently, their production has been gradually slowed down because of large wastage of energy in the form of heat produced along with light[28]. They are being replaced by compact fluorescent Lamps (CFL). CFLs are up to 4 times more efficient than incandescent bulbs and are also known as energy-saving bulbs[29]. But CFLs are toxic as they contain mercury[27]. Light Emitting Diodes (LEDs) are becoming popular due to the advancement in semiconductor technology. They are more efficient than CFLs. Table 2. compares the annual energy consumption and cost saving of various lighting technologies. It is assumed that the appliances are used 8 hours per day for the whole year. LED bulbs consume about 87% less energy and helps in saving ₹ 1642 annually as compared to conventional incandescent lamps. The three lighting bulbs are shown in Fig. 7.

Figure 7 (a) Incandescent (b) CFL (c) LED Bulbs

B. Ceiling Fan

Ceiling fans have a major contribution in electricity consumption especially in regions having hot climate like Aligarh. April, May, June and July are the hottest months of the year. Generally, ceiling fans are used almost in all months except cold months like November, December, January and February. Historically, AC induction motors are being utilised in ceiling fans because of their durability, simple construction and cheapness. Maximum efficiency in induction motor is obtained when slip is close to 0 (fig. 8(a)). But higher slip is preferred for delivering increased torque for higher loads which eventually decreases the efficiency. Brushless Direct Current (BLDC) motors are replacing induction motors because of their higher efficiency and performance[30]. Linear torque speed characteristics of BLDC motor enables operation at all speed with rated load (Fig. 8(b)). Table 2. compares the annual energy consumption and cost saving of BEE star rated ceiling fans with induction and BLDC motor technology. It is assumed that the fan runs for 12 hours per day for 240 days in a year. 5 star rated ceiling fan with BLDC technology consumes about 57 % less energy and saves Rs. 805 annually as compared to a regular fan.

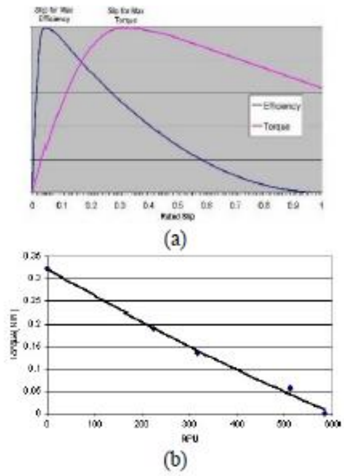

Figure 8. (a) Efficiency & Torque slip characteristics of AC induction motor (b) Torque speed characteristics of BLDC motor

Table 1. Energy consumption and cost saving of 1400 lumen lighting appliances

Company	Product code	Type	Power (W)	Annual Energy consumption (kWh/yr)	Rated lifetime (hrs)	Annual cost saving (Rs.)
Philips	925209344231	Incandescent	100	292	1000	0
Philips	871869641923601	CFL	20	58.4	25000	1518
Philips	910503910118	LED batten	18	52.56	25000	1556

Philips	046677281892	TFL	17	49.64	24000	1575
Philips	929001195771	LED	13.5	39.42	25000	1642

Table 2. Energy consumption and cost saving of ceiling fans (210 m3/min air delivery)

Company	Model	Motor technology	BEE star rating	Power consumption (W)	Annual energy consumption (kWh/yr)	Annual cost saving w.r.t. regular (Rs.)
Crompton	Cool breeze	Induction motor	Regular	75	216	0
Crompton	Cool breeze plus	Induction motor	3	56	161.28	356
Crompton	Empower 50	Induction motor	5	50	144	468
Crompton	Nstar	BLDC	5	32	92.16	805
Gorilla	Effico	BLDC	5	32	92.16	805

C. Refrigerator

Domestic refrigerators are one of the important home appliance manufactured because of their usage in refrigeration[31]. They consist of a cabin which is artificially kept cool and used for storing food and drink. They are marketed in various sizes and configurations in two technologies namely: Direct cool (DC) and Frost free (FF). DC refrigerators produce cooling effect by natural convection process and require manual defrosting of the interior. Whereas in FF or auto-defrost refrigerators, evaporator is automatically defrosted by a defrost heater mounted on it. They have better temperature management than direct cool refrigerators. But at the same time, auto defrost technology consumes more energy than direct cool technology because of extra heating element. Table 3. compares the annual energy consumption and cost saving of BEE star-rated 260 litre De-Frost refrigerators. 5 star rated LG GL-I302RPZW model is the most energy efficient and saves Rs. 1007 annually with respect to base model.

Table 4. compares the same for BEE star-rated 183 litre Direct Cool refrigerators. 5 star rated Samsung RR20M2Y2XU2/NL model consumes least energy and saves Rs. 1131 annually with respect to base model. The annual energy consumption in both cases is calculated by Bureau of Energy Efficiency (BEE)[26].

D. Air Conditioning System

Air Conditioning system (ACs) contribute heavily in energy consumption during the hotter months of the year. They control the heating within a room or location. The choice of ACs depend upon a number of factors including the area to be cooled, total heat generated inside, etc. Generally, decentralised AC systems are used in small houses which consist of individual units that control the heating/cooling of the room. Window ACs are commonly used for single rooms. All the components like compressor, evaporator, condenser etc. are fitted in a single unit. Cooling Seasonal Energy Consumption (CSEC) is the total electrical energy consumed by an appliance when operated in active mode for cooling.

Table 5. compares CSEC and corresponding cost saving of 1.5 ton BEE star rated window AC. Ton is used to represent the cooling capacity of AC. 5 star rated models are found to be most cost as well as energy saving as compared to other models.

Split AC consists of two main units namely: outdoor and

Table 3. Energy consumption and cost saving of de-frost refrigerators (260 l)

Company	Product code	star rating	Annual energy consumption (kWh/yr)	Annual cost saving w.r.t. base star (Rs.)
Samsung	RR19J20A3SE/TL	1	304	0
Samsung	RR19M24A2RJ/NL	2	254	325
Samsung	RR20N282ZR3/NL	3	189	748
Samsung	RR20M272YD2/NL	4	162	923
Samsung	RR20M2Y2XU2/NL	5	130	1131

Table 4. Energy consumption and cost saving of direct cool refrigerators (183 l)

Company	Product code	Star rating	Annual energy consumption (kWh/yr)	Annual cost saving w.r.t. base star (Rs.)
Whirlpool	FF 2D 305 3S	2	318	0
LG	GL-C302RPZU	3	253	423
LG	GL-I302RTNL	4	198	780
LG	GL-I302RPZW	5	163	1007

Table 5. Cooling seasonal energy consumption & cost saving of 1.5 ton window AC

Company	Product code	Star rating	Power input (W)	CSEC (kWh/yr)	Annual cost saving w.r.t. base star (Rs.)
Videocon	VWB52	2	1840	3312	0
Videocon	VWF53	3	1750	3150	1053
Videocon	VWL55	5	1505	2709	3920
Blue star	2W18GAR	2	1910	3438	0
Blue star	3W18LC	3	1730	3114	2106
Blue star	4WAE181YGT	4	1620	2916	3393
Blue star	5W18GBT	5	1500	2700	4797
Voltas	4011243	2	1831	3295.8	0
Voltas	4011264	3	1750	3150	948
Voltas	4011238	5	1540	2772	3405

indoor unit. The outdoor unit is installed on the exterior wall and the indoor unit is installed inside the room. The indoor unit comprises of evaporator, cooling fan and cooling coil. Table 6. compares CSEC and corresponding cost saving of 1.5 ton BEE star rated split AC. 5 star rated LG KS-Q18MWZD model is the most energy efficient having cost saving of Rs. 1638 with respect to base model. It is assumed in both cases that the ACs are being used for 10 hours in a day for 6 months in a year.

Table 6. Cooling seasonal energy consumption and cost saving of 1.5 ton split AC

Company	Product code	Star rating	Power input (W)	CSEC (kWh/yr)	Annual cost saving (Rs.)
LG	KS-Q18 BWXD	3	1580	2844	0
LG	BSA18 BE YD	4	1540	2772	468
LG	KS-Q18 MWZD	5	1440	2592	1638

E. Water Heater

Domestic use of water includes watering garden, drinking, cooking, etc. Heated water is also required for many purposes like bathing & washing clothes. Hence, water heaters are fitted in homes for supplying required hot water. Two types of water heaters are available in the market namely: tank-type and tank-less type. In the present analysis, we are using storage tank type water heaters with electrical heating system. They are insulated from outside in order to minimise heat loss due to discharge of hot water from the tank. Continuous electricity supply is needed for maintaining constant temperature of the stored water. Table 7. compares the annual energy consumption and cost saving of BEE star rated 25 litres storage tank type water heaters. 5 star rated AO smith HSE-SHS-025 model is the most energy efficient and saves Rs. 682 annually with respect to base model. It is assumed that the heater is running in standby mode only for 4 hours in a day for 150 days in a year. Standing loss is the energy consumed by the filled water heater connected to electricity supply when no water is drawn for 24 hours.

F. Washing machine

A conventional washing machine comprises of number of user chosen options for washing like duration of wash, type of washing, etc. Semi-automatic model comprises of two tubes i.e. one for washing and the other for drying. In semi-automatic models, clothes have to be manually put in the drier after washing. Nowadays, fully-automatic models are replacing semi-automatic ones. No manual intervention is required between washing and drying in the former model. However, in the present study fully automatic models are considered for comparison. They come in two variants namely: front loaded and top loaded. In front loading, the laundry is placed from front side whereas laundry is placed from the top in top loading model.

Table 7. Energy consumption and cost saving of 25L storage tank type water heater

Company	Product code	Star rating	Rated power(W)	Standing loss(kWh)	Annual energy consumption (kWh/yr)	Annual cost saving (Rs.)
AO smith	HSE-HAS-PLUS-025	2	2000	0.680	408	0
AO smith	HSE-HAS-025-LHS	3	2000	0.618	370.8	242
AO smith	HSE-SES-025	4	2000	0.550	330	507
AO smith	HSE-SHS-025	5	2000	0.505	303	682

Table 8. compares the annual energy consumption and cost saving of 8kg fully automatic front-loaded washing machines. Average cycle duration is assumed to be 60 minutes and machine runs for 2 cycles per day for 100 days in a year. Whirlpool Supreme Care 8014 is the most energy efficient and saves Rs. 364 annually as compared to base model.

Table 8. Energy consumption and cost saving of 8 kg front loaded Washing machine

Company	Product code	Annual energy Consumption (kWh/yr)	Annual cost saving (Rs.)
LG	FH2G6TDNL42	420	0
Samsung	WW80J5410GS	400	130
Whirlpool	SUPREME CARE 8014	364	364

Table 9. compares the annual energy consumption and cost saving for 8kg fully automatic top-loaded washing machines. Average cycle duration is assumed to be 30 minutes and machine runs for 2 cycles per day for 100 days in a year. LG T9077NEDL1 is the most energy efficient and saves Rs. 74 annually as compared to base model.

Table 9. Energy consumption and cost saving of 8 kg top loaded Washing machine

Company	Product code	Annual energy Consumption (kwh/yr)	Annual cost saving (Rs.)
IFB	TL-SGDG AQUA	46.5	0
Lloyd	LWMT80TL	42	29
LG	T9077NEDL1	35	74

G. Television

Television (TV) is a medium of telecommunication which is used for transmitting information in the form of moving images and sound. It is used in broadcasting programs related to news, education and entertainment. Various types of TVs are available in the market namely: Cathode Ray Tube (CRT), Liquid Crystal Display (LCD), Light Emitting Diodes (LED), Plasma & Organic Light Emitting Diodes (OLED). Smart TVs are being investigated in our analysis. Smart TVs are televisions which are connected with the Internet. Along with normal TV, the user can surf internet, stream music and videos, etc. Stand by power is the power consumed by the appliance when it is switched OFF. On mode power consumption is the power consumed by the appliance when it is ON. Table 10. compares the annual energy consumption and cost saving of BEE star rated 43 inch smart TV. 5 star rated LG 43LW300C-TA is the most energy efficient and saves Rs. 344 annually with respect to base model. The annual energy consumption is calculated by Bureau of Energy Efficiency (BEE).

Table 10. Energy consumption and cost saving of 43 inch smart TVs

Company	Product code	Annual energy consumption (kWh/yr)	Annual cost saving (Rs.)
LG	43LJ554T-TA	135	0
LG	43LV640S-TB	121	91
LG	43LX761H-GA.ATRYLH	107	182
LG	43LK5260PTA	93	273
LG	43LW300C-TA	82	344

H. Microwave oven

Microwave oven is an important electrical appliance used in kitchen for cooking, baking and reheating foods. It is based on the principle of heating by electromagnetic radiation. When food is placed inside the oven, it gets heated due to interaction with oscillating electromagnetic waves. Ovens come in three different variants namely: Solo, Grill and Convection.

Solo microwave ovens are the basic models which are used for simple cooking and reheating. Table 11. compares the annual energy consumption and cost saving of 20 litres solo microwave ovens. It is assumed that the oven runs for 10 minutes in a day for the whole year. Haier HIL2001MBPH and LG MS2043BP are the most energy efficient models and save Rs. 178 annually with respect to base model.

Table 11. Energy consumption and cost saving of 20L Solo Microwave oven

Company	Product code	Annual energy consumption (kWh/yr)	Annual cost saving (Rs.)
Samsung	MW73AD-B/XTL	69.96	455
IFB	20PM2S	48.67	139
LG	*MS2043BP*	42.58	178
Haier	HIL2001MBPH	42.58	178

Grill type microwave ovens come with additional grilling accessories along with simple cooking and reheating.
It has heating coils that helps in grilling, toasting and roasting foods. Table 12. compares the annual energy consumption and cost saving of 20 litres grill type microwave ovens. It is assumed that the oven runs for 10 minutes a day in grill mode only for the whole year. Whirlpool MAGICOOK 20L Deluxe is the most energy efficient and saves Rs. 118 annually with respect to base model.

Table 12. Energy consumption and cost saving of 20L Grill Microwave oven

Company	Product code	Annual energy consumption (kWh/yr)	Annual cost saving (Rs.)
Onida	MO20GMP12B	60.83	0
IFB	20PG4S	60.83	0
Panasonic	NN-GT221WFDG	60.83	0
Whirlpool	MAGICOOK 20L DELUXE	42.58	118

In Convection type microwave ovens, fan is also placed along with heating element to circulate hot air for faster cooking. They are mostly used for baking foods. Table 13. compares the annual energy consumption and cost saving of 20 litre convection type microwave oven. It is assumed that the oven runs for 10 minutes in a day in convection mode only for the whole year. Godrej GME 720 CP1 PM and Panasonic NN-CT254BFDG are the most energy efficient and saves Rs. 396 annually with respect to base model.

Table 13. Energy consumption and cost saving of 20L Convection Microwave oven

Company	Product code	Annual energy consumption (kWh/yr)	Annual cost saving (Rs.)
IFB	20BC4	133.83	0
Whirlpool	MAGICOOK 20L	121.67	79
Panasonic	NN-CT254BFDG	73	396
Godrej	GME720CP1PM	73	396

III. CASE STUDY

A modern house in the civil lines colony of Aligarh district of UP is investigated. Table 14. enumerates the various types of home appliances installed in the house.

Table 14. Home appliances installed in the house

Type of appliance	Total in number
Lighting system	10
Ceiling fan	4
Refrigerator	1
Washing machine	1
Water heater	1
Colour TV	2
AC	3
Microwave oven	1

Energy consumption and cost saving chart is developed using the data from the methodology discussed above. On the basis of efficiency, we have taken the following three cases:

Case i. All appliances are least efficient.

Case ii. All appliances are most efficient.

Case iii. Combination of appliances of type between (i) and (ii).

IV. RESULTS AND DISCUSSION

Efficiency based annual energy consumption and corresponding cost saving of different appliances is given in Fig. 9 and 10 respectively. Among all the appliances, light bulbs, ceiling fans and refrigerators have the highest % energy and cost saving from the most efficient models i.e. 86%, 57% and 57% respectively. Considering the appliances being utilised in the house

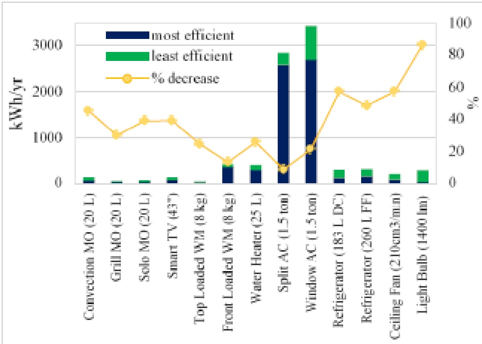

Fig. 9. Annual energy consumption of most and least efficient appliances

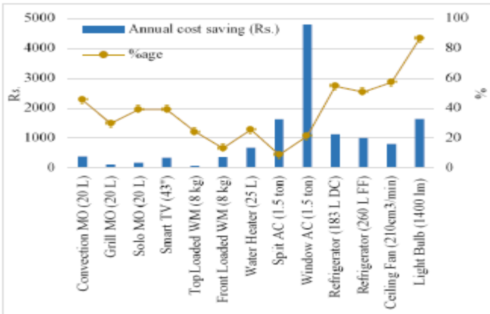

Figure 10. Annual Cost saving of most efficient appliances

described above, Fig. 11 shows annual energy consumed and running cost for the three cases. Switching from appliances used in Case (i) to Case (ii) and (iii) resulted in reduction of 28% and 37% respectively in both energy consumed and running cost.

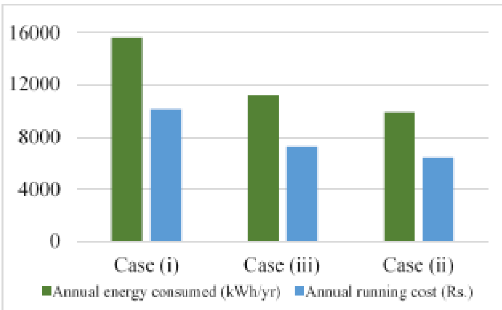

Figure 11. Annual energy consumed and cost saving chart of all the above cases

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V. CONCLUSION

In our analysis, we compared the annual cost saving and energy consumption of eight common home appliances used in homes. Following conclusions are drawn from the analysis:

- The above eight appliances analysed contribute almost all of the residential energy consumed in India. And in addition, only five appliances namely AC, washing machine, water heater, refrigerator and light bulb represent about 80% of total energy consumed.
- ACs and washing machines are among the most electricity guzzling appliances.

- Light bulbs have the highest potential of energy and cost saving from the most efficient models followed by ceiling fans and refrigerators.

- For the house we considered, changing all conventional appliances with most efficient ones resulted in about 37% reduction of annual running cost as well as electricity consumption.

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AUTHOR'S PROFILE

Md Abdullah Ansari, is currently pursuing Bachelor of Technology in Electrical engineering from Aligarh Muslim University, Aligarh, India. His research interests include Multi level DC-AC Inverters.

Arshad Mohammad, received Bachelor of engineering in electrical engineering and Master in technology in electrical engineering with specialization in instrumentation and control from Aligarh Muslim University, Aligarh, India in 2013 and 2015 respectively. Currently he is pursuing PhD in power system. His research interest includes energy management and monitoring in smart home, smart grid and micro-grid.

Mohd Tariq, obtained a B. Tech in electrical engineering from Aligarh Muslim University and M.Tech in machine drives and power electronics from the Indian Institute of Technology (IIT)-Kharagpur. He pursued his Ph.D. from Nanyang Technological University, Singapore. Before joining his PhD, he has worked as a Scientist in an autonomous institute (NIOT, Chennai) under ministry of earth sciences, govt. of India and also worked as an Assistant Professor at National Institute of Technology (NIT) – Bhopal, India. Currently, he is working as an Assistant Professor at Department of Electrical Engineering, Aligarh Muslim University, Aligarh, India.

Ahmed Riyaz, received his M.Tech. (Power System & Drives) and B.Tech. (Electrical) Engineering from the Deptt. Of Electrical Engg., Aligarh Muslim University, Aligarh, India in 2009 and 2007, respectively. He has worked as Senior Research Fellow in an MHRD sponsored research project at IIT Roorkee developing online open source simulation tools. He has research and teaching experience of ten years. He is currently working as faculty member at BGSB University and developed multi-phase drives lab simultaneously handling many key responsibilities in administration.

He is also Nodal Officer (Academics) for a World Bank sponsored project worth one hundred ten million Indian Rupees at BGSB University. His area of research includes Multi-phase (more than three-phase) Electric Drives and Power Electronic converters.