Energy Consumption Attributes in Residential Buildings- A Case Study of Replacing Conventional Electrical Appliances with Energy Efficient Appliances

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Abstract- Increasing world energy demand is resulting in degradation of environment causing global warming, ozone layer depletion, climate change and exhaustion of our nonrenewable energy resources. This paper reviews different studies about energy consumption in residential buildings and different variables influencing the energy consumption. This paper also reviews the potential and challenges uprooting in the usage of renewable energy sources. The payback period in a residential building varied from 213 days to 502 days for 3BHK dwelling and 213 days to 556 days for 2BHK Dwelling if various appliances are replaced with energy efficient ones. Replacing the lighting appliances came out to be most economical in respect of the consumer, while if TV, Fan and Light are replaced, the initial cost increases but reduction in energy consumption is considerable. This study shows retrofitting of old buildings, energy conservative behavior of occupants, motivating and educating people for the use of renewable energy sources and use of energy efficient appliances are found to be the most efficient steps to reduce overall energy consumption by residential building sector.

Keywords- Residential Building, Energy consumption, Energy Efficiency, Energy use, Energy audit, Household behavior, Renewable energy sources.

1. Introduction

According to the statistical review made by British Petroleum primary energy consumption in India have elevated by 5.2% in 2015[1]. Presently the highest end use of energy is in the form of electricity and the larger part of its production comes from the non- renewable sources of energy i.e. thermal and nuclear. The increasing demand obligates either to efficient use of nonrenewable reserves or to divert the sources of energy production. Various Policies are acknowledged worldwide to emphasize Green technology with coordinated planning and strategies at regional and national level. [2,3,4]. Furthermore, the state incentives enhance the deployment of renewable energy[5]. Based on the reports by Central Electricity Authority, India [6] figure 1 shows the percentage of production of electricity from non-renewable energy sources of the total electricity produced in each state of India

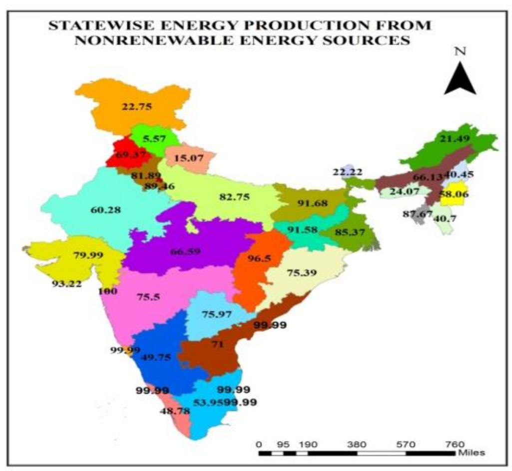

Fig1. State-wise electric energy production from non-renewable energy sources

2. Alternate Sources of Energy:

There is numerous alternate renewable energy sources namely solar, wind, hydro biomass power, cogeneration bagasse, waste to energy and geothermal. India, due to its favorable location, has a vast wealth of Solar Energy [7]. Based on the report of Ministry of Statistics and Program of Implementation [8] fig 2 shows the potential for the production of energy from renewable energy sources in each state of India. These resources are most beneficial for rural areas. For instance, In Pani Para village of Bangladesh electricity demand can be met by using membrane distillation poly-generation along with additional cooking fuel [9]. However these sources entail many challenges and issues, for example wind and small hydro power projects have significant effects on the local ecosystem. The setting up of the transmission lines, hauling of the construction cranes for setting up wind masts as well as hauling the wind masts themselves require construction of roads, the large scale destruction of forests, habitats and soils, leading to landslides and massive soil erosion in high rainfall areas . Another important issue associated with the development of renewable energy is with respect to land. Renewable energy projects are set up in the forest owned by revenue/government or private land. Availability of land for setting up renewable energy projects is a vexed issue. For example, in Karnataka many of the high wind potential sites fall in the forest lands and the non-availability of non-forest land co-extensive to forest land for compensatory afforestation has been spelled out as one of the major problems in the state as reported by Ministry of New and Renewable Energy [10]. Skill gaps such as design and fabrication of biomass gasifires, erection and commissioning of large-scale biomass plants, feedstock planning and management of biomass plants, design skills to match wind speeds and capacity of turbines, etc. also emanates in the sector.

Lastly with the increasing pace of renewable capacity addition in the country and the potential of the sector, massive investments are required from government and private sources. However, it is seen that the budgetary investments in renewable energy in India have not been coeval with the sector's growth as reported by The Energy and Research Institute in 2014 [11].

Fig 2. State-wise potential of renewable energy in India

The electricity produced by the non-renewable resources is 216,455 MW while from renewable it is 85,632 MW [6]. Although the potential from renewable was estimated to be 896603 MW [8] but this potential was calculated without considering the challenges associated with them. Therefore, another alternative is to reduce the demand which can be achieved by improving the energy management and efficiency in different buildings [12].

3. Elements of Efficient Energy Consumption in Residential Buildings

The previous studies have shown various factors that affect the electricity consumption in residential buildings. These factors can be classified as occupant behavior, dwelling, appliances and climate. The factors are explained in the following sub-section.

3.1. Occupant behavior

Behavioral change of the occupant has energy saving potential comparable, and in most cases it may amount to higher savings than that of the technological solutions. The most salient feature of the behavioral change is that it is largely at no cost, does not need any hi-tech knowledge, readily applicable to both the new and existing buildings, largely appreciated by many but it has been observed that the occupant does not realize as a measure for energy savings. The number of occupants, their age, behavior towards light usage, heating ventilation air conditional (HVAC) usage, and income etc. affect the behavior towards saving of the energy. These factors have been studied extensively by various authors and have explained the positive as well as negative effect on consumption of the electricity.

(3.1.1) Number of occupants

Most of the research showed a positive effect on the consumption of electricity with the increase of the members in a family. Tiwari [13] recognized that five member families in India have incurred 23% more electricity expenditure compared to a two-member family. Leahy and Lyons [14] concluded that one member Irish households consumed 19% less electricity per week than a two member household. Genjo et al. [15] actualized that electricity consumption for lighting and appliances increased by 230kW per person with the growth of the household in Japan.

(3.1.2.) Age of the occupants

In a study of The Netherland households, Brounen et al. [16] concluded that one-fifth of the total electricity was consumed more with children and this trend effect increased with the increase in the children's age. Flippini and Pachauri [17] found that Indian households with younger household responsible person (HRP) with age less than 45 years consumed less electricity than the households with older HRP.

(3.1.3) Light usage

The failure of the human component can defeat the whole mission of the energy savings in spite of having technology advancement. This makes occupancy behavior as one of the weakest links in the energy conservation. Masoso and Grobler reported that the biggest consumers of electricity were found to be air conditioning systems, followed by equipment that were left ON unnecessarily at the end of day (mostly computers), then lighting and the maximum wastage is during the working hours when no one is [18]. Lindelöf and Morel [19] studied light switching patterns of occupants during working hours and observed that due to the location of the light switch at the door (out of arm's reach from working desk), lights are left on all day even when they are not needed. This is waste of electricity during the working hours.

(3.1.4) HVAC usage

The energy consumption of air conditioning is the largest among other appliances. Langevin et al [20] demonstrated that the use of personal heating/cooling devices could allow for an increase in the thermostat set point enhancing thermal comfort, while reducing the total energy use. Larsen and Nesbakken [21] estimated that Norwegian households with portable electric heaters or central heaters consumed 3700 kWh per annum extra energy than the households without them. Tso and Yau [22] concluded an average of 59% more energy consumed by air-conditioned households than the ones without them.

(3.1.5) Income of household

Literature showed a positive effect of income over energy consumption. According to Yohanis et al.[23] in Northern Ireland the households with income over 30,000 Euros per annum consumed 2.5 times more energy than the households with the income less than 10,000 Euro per annum. In Japan, Genjo et al. [15] concluded that the energy consumption increased linearly with the increase in income increase.

3.2. Dwelling attributes

The various component falls under this category namely type, age, number of rooms, floor area urban density and building orientation etc play a significant role in the energy efficiency of the buildings. Tiwari [13] concluded that the detached Indian houses consumed significantly higher amount of energy than other house types. He also reported that with every additional room 11% more energy is consumed. A positive effect of the number of rooms was also established by Leahy and Lyons [14] and Bedir et al. [24] in Irish and Dutch dwellings, respectively. Literature also showed a constructive effect of floor area with the energy consumption. Neilsen [25] reported that in Denmark with 1% addition in floor area, the energy consumption increases by 0.6%. As stated by Filippini and Pachauri [17] with extension of 1% floor area there was 0.2% more energy consumed in Indian urban dwellings. Delmastro et al. [26] determined that an efficient urban planning can enhance the energy savings. They also concluded that orientation of the buildings should be fixed from the beginning with the preference of an east-west orientation to avoid urban canyon and shadowing effects.

3.3 Appliances

Appliances like computers, ovens, washing machines, dishwashers, HVAC and televisions etc play a compelling role in the consumption of electricity. In China, Zhou and Teng [27] determined that households with computers consumed 10% more electricity than the households without them and 22% higher energy consumption in the households with refrigerators. In addition to computers and refrigerators, McLoughlin et al. [28] observed that the households with television consumed more energy than without them. Larsen and Nesbakken [21] established that in Norway households with dishwasher consumed 2015kWh of more energy per year as compared to the households without them. Other appliances like vacuum cleaner, swimming pool pumps, spas, washing machines dryers add up in the energy consumption of a household.

3.4 Climate

Papakostas et al. [29] stipulated that the significant warming climate of the whole world due to the global climate change is considered to have strong effects on a building's energy requirement or usage as their heating and cooling needs are related to the temperature conditions and weather variations. Under the conditions of changing climate, especially in summer, the buildings will consume more energy. Increase in temperature and extreme weather events, temperature swings, changes in relative humidity and solar radiation should be taken into account to ensure that current and future buildings are able to adapt to these changes and thus minimize the potentially destructive impacts such as energy use and carbon emissions. This will lead to significant increase or large inter-annual fluctuations of extreme cooling energy consumption as well as increasing average energy consumption.

4. Case Study of Energy Efficient Appliances and Their Cost:

In this study the primary data related to appliances & their numbers, usage and price per unit of electricity (kWh) consumed in residential building situated in Mouje Dhayari, Pune district, Maharashtra, India were used [30]. For calculating the cost of appliances and energy savings, the following points were considered:

- The energy star rated fans with 1200mm sweep was taken as replacement for ordinary fan having 1200mm sweep with maximum Power consumption 75W.
- Lighting appliances were replaced on the basis of light output of conventional tubes with LED tubes.
- Fans, TV and Tube lights were replaced with energy efficient appliances.
- The cost recovery time (CRT) was calculated as:

$$CRT\ (days) = \frac{cost\ of\ energy\ efficient\ appliance - cost\ of\ conventional\ appliance}{\left(energy\ consumed(\frac{Whr}{day})\ conventional\ appliances - energy\ efficient\ appliances\right)}$$

Table 1. Comparative energy and cost analysis of the use of appliances for 3BHK apartment

Sr. No	Electricity Point	Appliances	Cost of conventional /Energy efficient appliance per unit (INR)	No.	Total Cost conventional / Energy efficient appliance (INR)	Watts/ appliance: Conventional / Energy efficient	Usage (hours/ day)	Appliance Whr/day: conventional /energy efficient
1	Ceiling Fan point	Fan	1929/ 2380	4	7716/ 9520	75/50	4.5	1350/ 900
2	5A Switch	Other Appliances	60/60	5	300/300	40/40	3	600/600
3	5A half plug point		84/84	3	252/252	20/20	1	60/60
4	15A switch	Kitchen Appliances	86/86	2	172/172	1000/1000	0.5	1000/1000
5	Exhaust	Fan	1300/1300	3	3900/3900	60/60	0.5	90/90
6	TV point	TV	9500/15900	2	19000/31800	120/35	6	1440/420
7	Lighting	Tube light/LED	147/800	9	1323/7200	40/20	17	6120/3060
			Total		32663/ 53144			10660/6130

The total energy savings (KWh) by energy efficient appliances i.e. LED, TV and fan was observed to be 42.49%. The savings in the electricity comes out to be 4.53 kWh per day and in terms of monetary value, it was found to be INR 40.77 per day for single unit of 3BHK. The contribution of TV in the increased cost was found to be highest (62.49%) among the appliances replaced by energy efficient appliances followed by lighting appliances (28.69%) and fan (8.81%), respectively. Similarly the contribution of lighting appliances is maximal (67.54%) in energy savings/day followed by TV (22.52%) and fan (9.93%), respectively.

The cost recovery time for the different combinations is given below:

- Lighting appliances: 213 days
- Lighting appliances and fan: 243.1 days
- Lighting appliances, fan and TV: 502 days

Table 2 Comparative energy and cost analysis of the use of appliances for 2BHK apartment

Sr. No.	Electricity point	Appliances	Cost of conventional /Energy efficient appliance per unit (INR)	No.	Total Cost conventional/ Energy efficient appliance (INR)	Watts/appliance : Conventional/ Energy efficient	Usage (hours/ day)	Appliances Whr/day: Conventional/ Energy efficient
1.	Ceiling fan Point	Fan	1929/2380	3	5787/7140	75/50	4.5	1012.5/675
2.	5A switch	Other Appliances	60/60	4	240/240	40/40	3	480/480
3.	5A half plug point		84/84	2	168/168	20/20	1	40/40
4.	15A switch	Kitchen Appliances	86/86	2	172/172	1000/1000	0.5	1000/1000
5.	Exhaust	Fan	1300/1300	2	2600/2600	60/60	0.5	60/60
6.	TV point	TV	9500/15900	2	19000/31800	120/35	6	1440/420
7.	Lighting	Tube light/ LED	147/800	7	1029/5600	40/20	17	4760/2380
			Total		28996/47720			8792.5/5055

The total energy savings (kWh) by energy efficient appliances i.e. LED, TV and fan is 42.50%.The savings in electricity was computed to be 3.74 kWh per day and in terms of monetary value, it was found to be INR 33.66 per day for single unit of 2BHK. The contribution of TV in the increased cost was found to be highest (68.36%) among the conventional appliances replaced by energy efficient appliances followed by lighting appliances (24.41%) and Fan (7.23%), respectively. Similarly contribution of lighting appliances is maximal (63.64%) in energy savings/day followed by TV (27.27%) and fan (9.09%), respectively.

The cost recovery time for different combinations is given below:

- Lighting appliances: 213 days
- Lighting appliances and Fan: 242.2 days
- Lighting appliances, Fan and TV: 556.64 days

5. Conclusion

In this paper a review on energy efficiency of residential building is carried out. It includes the installed capacity of electricity generation source-wise and state-wise was discussed along with the renewable potential with their constraints.

Following are the salient points of the study:

- Energy audit of buildings is very helpful tool for assessing the energy usage of the building and should be promoted by the govt. organizations.
- The study showed that the reduction in energy consumption due to energy efficient appliances was found out to be substantial leading to lesser consumption of non-renewable resources for energy demand for a given population.
- The recovery time of additional cost is same for 3BHK and 2BHK dwellings when only conventional lighting appliances are replaced i.e. 213 days and 243 days when conventional lighting appliances in combination with fan were replaced with energy efficient appliances.
- As the price per unit of electricity decreases, the cost recovery time increases which can influence the behavior of occupants towards energy savings.
- Energy efficient appliances with star ratings were found to be effective.

References

[1] Statistical review of world energy, British Petroleum, 65th Edition, 2016.

[2] E. Irmak, M.S. Ayaz, S.G. Gok and A.B. Sahin, “ A survey on public awareness towards renewable energy in Turkey”, International Renewable Energy Research and Application Conference, Milwaukee, pp. 932- 937, 19-22, October 2014.

[3] S. Han and H.W. Shin, “Policy trends of renewable energy in Korea”, International Renewable Energy Research and Application Conference, Milwaukee, pp. 218-221, 19-22, October 2014.

[4] O.T. Winaro, Y. Alwendra and S. Mujiyanto, “Policies and Strategies for renewable energy development in Indonesia”, International Renewable Energy Research and Application Conference, Birmingham, pp. 270-272, 20-23 November 2016.

[5] D. Sangroy and J.K. Nayak, " Evaluating the role of state incentives in the deployment of wind energy in India", International Journal of Renewable Energy Research, Vol. 1, No. 1, pp 14-28 , October 2015.
[6] All India Installed Capacity of Power Stations, Central Electricity Authority, 2016.
[7] Anamika and N. Kumar, " Solar resource estimation based on correlation matrix response for Indian geographical cities, International Journal of Renewable Energy Research, Vol. 6, No. 2, pp 695-701 , February 2016.
[8] Energy Statistics, Central Statistical Organization, Ministry of Statistics and Program of Implementation, Government of India, 2016
[9] E. U Khan and A.R. Martin, " Hybrid renewable energy with membrane distillation polygeneration for rural households in Bangladesh Pani Para village Case study", International Renewable Energy Research and Application Conference, Milwaukee, pp. 365- 368, 19-22 October 2014.
[10] Strategic Plan for New and Renewable Energy Sector for the period 2011-17, Ministry of New and Renewable Energy Government of India, 2011.
[11] P R Krithika and S. Mahajan, "Governance of renewable energy in India: Issues and challenges", The Energy and Research Institute, TERI-NFA Working Paper Series No. 14, March, 2014.
[12] D. Sangroy and J.K. Nayak, "Development of wind energy in India", International Journal of renewable energy research Vol. 5, No. 1 pp 1-13, November 2015.
[13] P. Tiwari, "Architectural demographic and economic cause of electricity consumption in Bombay", Journal of Policy Modeling Vol. 22, No. 1 pp. 81–98, 2000.
[14] E. Leahy and S. Lyons, "Household Energy Use and Appliance Ownership in Ireland", Energy Policy, Vol. 38, No. 8, pp. 4265-4279, February, 2009.
[15] K. Genjo, S. Tanabe, S. Matsumoto, K. Hasegawa and H. Yoshino, "Relationship between possession of electric appliances and electricity for lighting and others in Japanese households", Energy and Building, doi:10.1016/j.enbuild.2004.06.025, Vol. 37, No. 3, pp. 259–272, 2005.
[16] D. Brounen, N. Kok and J. M. Quigley, "Residential energy use and conservation: economics and demographics", European Economic Review, Vol. 56, No. 5, pp. 931-945, July 2012.
[17] M. Filippini and S. Pachauri, "Elasticities of electricity demand in urban Indian households", Energy Policy, Vol. 32, No. 3, pp. 429–436, February 2004.
[18] O.T. Masoso and L.J. Grobler, "The dark side of occupant's behavior on building energy use", Energy and Buildings, Vol. 42, No. 2, pp. 173–177, February 2010.
[19] D. Lindelöf and N. Morel, "A field investigation of the intermediate light switching by users", Energy and Buildings, Vol. 38, No. 7, pp. 790-801, July 2006.
[20] J. Langevin, J. Wen and P. L. Gurian, "Including occupants in building performance simulation: integration of an agent-based occupant behavior algorithm with Energy Plus", ASHRAE/IBPSA-USA Building Simulation Conference, Atlanta, GA, 10–12 September 2014.
[21] B. M. Larsen and R. Nesbakken, "Household electricity end-use consumption: results from econometric and engineering models", Energy Economics, Vol. 26, No. 2, pp. 179-200, March 2004.
[22] G. K.F. Tso and K. K.W Yau, "A study of domestic energy usage patterns in Hong Kong", Energy, Vol. 28, No. 15, pp. 1671-1682, December 2003.
[23] Y. G. Yohanis, J. D. Mondol, A. Wright and B. Norton, "Real-life energy use in the UK: how occupancy and dwelling characteristics affect domestic electricity use", Energy and Buildings, Vol. 40, No. 6, pp. 1053-1059, 2008.
[24] M. Bedir, E. Hasselaar and L. Itard, "Determinants of electricity consumption in Dutch dwellings", Energy and Buildings, Vol. 58, pp. 194-207, March 2013.
[25] L. Nielsen, "How to get the birds in the bush into your hand: results from a Danish research project on electricity savings", Energy Policy, Vol. 21, No. 11, pp. 1133–1144, November 1993.
[26] C. Delmastro, G. Mutani, M. Pastorelli, G. Vicentini," Urban Morphology and Energy Consumption in Italian Residential Buildings", International Renewable Energy Research and Applications Conference, Italy, pp. 1603-1608, 22-25, November 2015.
[27] S. Zhou and F. Teng, "Estimation of urban residential electricity demand in China using household survey data", Energy Policy, Vol. 61, pp. 394–402, October 2013.
[28] F. McLoughlin, A. Duffy and M. Conlon, "Characterising domestic electricity consumption patterns by dwelling and occupant socio-economic variables: An Irish case study", Energy and Buildings, Vol. 48, pp. 240–248, May 2012.
[29] K. Papakostas, T. Mavromatis and N. Kyriakis,"Impact of the ambient temperature rise on the energy consumption for heating and cooling in residential buildings of Greece", Renewable Energy, Vol. 35, No. 7, pp. 1376-1379, July 2010.
[30] R. Sharma and R.K. Jain, " Energy audit of residential buildings to gain energy efficiency credits for LEED certification", International Energy Systems and Applications Conference, Pune, pp. 718-722, November, 2015.