The Impact of the Energy Efficient Appliances on Occupant Behavior through Rebound Effect in residential buildings

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Abstratct

Energy efficient building is the only significant mitigation strategy to save energy in the residential buildings after the advent of energy crisis. Such buildings are not only designed on the principles of sustainability and energy efficiency but also are well equipped with modern efficient appliances for households. This leads towards the use of devices which involve technology and material that utilize minimum energy and give better output. Although these innovations are the step forward to the energy problem but it also creates an incautious use of energy on user behavior in Pakistan. It is deduced after experience that residents were used to be very careful about the use of incandescent bulb due to its impact of high energy consumption, whereas in era of energy efficient lights the influence of careful use of energy is lost due to the impact that these lighting fixtures are creating. Hence, this influence loss is causing same or more energy consumption, showing the presence of Rebound effect. This research paper aims to identify the effect of energy efficient appliances on user behavior through rebound effect and its mitigation. In order to trace the energy consumption habits, a target group of 5 houses is comparatively evaluated on before and after the use of energy efficient lighting fixtures particularly the "energy saver bulbs". The main findings of the study include presence of indirect rebound effect with the use of energy efficient lighting fixtures.

Key Words: Energy Efficient appliances, Occupant Behaviour, Rebound Effect

1. Introduction

The major challenges of current world are increased population, depletion of valueable energy resources and environmental deterioration [1]. These problems are major factors that have given rise to climate change all over the world. Energy efficiency is considered a useful strategy to cope with the phenomenon of climate change, especially in building sector [2]. It is necessary to discuss the famous equation i.e. I=PxAxT put forward in early 1970s to understand the background of the concept of energy efficiency. According to this mathematical formula, the human impact on environment is determined by three important elements which are population size (P), affluence (A), and technology (T) [3]. It can be deduced that with a certain increase in population and wealthy lifestyle i.e. affluence, the society requires ten times more efficient technology to reduce the human impact on environment which includes employment of renewable energy resources to fulfill the energy needs as well as reduction of CO_2 emissions. According to this formula, the societal impact on environment can be reduced up to 80% [4].

Building sector is important in this discussion as it is responsible for consuming one third of global energy resources and accounts for 30% CO_2 emissions. This makes building sector important target for application of energy efficiency measures [5]. In Pakistan, building sector consumes more than 50% of energy as compared to other sectors. (Fig.1) [6].

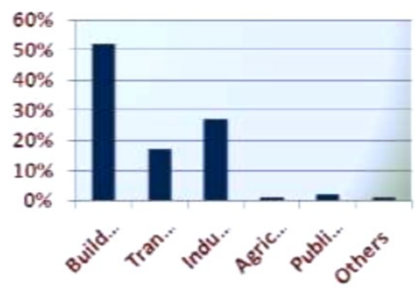

Fig. 1: Energy consumption breakdown sector wise: Pakistan [6]

It can be concluded that in Pakistan like any other developing country, energy crisis can be cope up by applying energy efficiency strategies in the buildings.

The concept of energy efficiency in buildings has changed many dimensions as it evolved with the passage of time. In spite of many dimensions, some common features in energy efficient buildings include well insulated walls, air tight envelope and window/door openings, efficient heating/cooling systems and energy efficient appliances [7]. By using simulation tools and energy efficient appliances the predicted energy required for space heating, cooling and lighting has been reduced considerably in recent decades. In spite of all the above mentioned strategies, still there is a considerable disparity between predicted and actual energy consumption of the buildings. Occupant behavior and user preferences are the main factors responsible for this disparity [8] [5]. This is the reason that occupant behavior and post occupancy survey have been the recent topics of discussion and research in the domain of energy efficient buildings.

This research is focused on the two aspects of energy efficient buildings; the energy efficient appliances (require less energy to provide services) specifically energy efficient lighting fixtures and the other one is occupant behavior and the impact of the former on the later in the context of Pakistan. It is important to mention here that residential buildings have been targeted in this research because residential buildings are huge consumers of energy and unlike commercial buildings cannot generate income. The scenario of electricity consumption in Pakistan by different sectors also ensures that achieving energy efficiency in residential building sector will considerably reduce the electricity consumption in Pakistan (Fig 2).

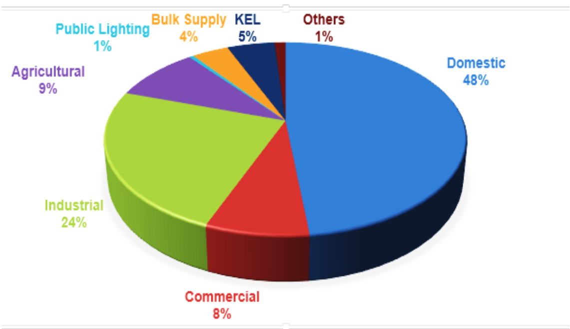

Fig.2: Domestic Sector is taking the major chunk of county's total electricity generation [9] [10]

1.2 Energy Efficient Lighting

Light is the medium for stimulating sense of sight and a basic necessity to function life. For a long period of time human beings have been dependent on natural sources of light such as sun, moon, thunder and fire etc. to function their lives. Daylighting had continued to be a prime source to light all types of buildings for centuries. It continued to be like this until the start of 20th century when there was a prominent development in electric sources of light. Another factor which stimulated the use of artificial lighting in the buildings of the construction of huge building structures (high rise office buildings) in the same time period. In 1960s, the use of artificial light sources declared to be primary source of providing light in buildings instead of daylight. This development was to promote the use of electric sources of light. The illuminance industry thus started with incandescent bulbs which require energy to process. The oil crisis in 1980s made people realize that reliance on fossil fuels for energy had its own limitations and first time people started to think about reducing energy use in buildings for heating cooling and lighting as well [11].

This led to the formation of bulbs with more proficiency and energy saving. The same evolution brings an immense change after the concept of fluorescent and LED lights which were considered as energy saving bulbs.

In Pakistan according to a Gallup survey carried out in 1987, 64% of the urban homes used incandescent bulbs for lighting, only 28% used fluorescent lights and 8% said they used them equally. Whereas in 2000 the situation was reversed 67% of all urban households said that they mainly use fluorescent tube light for lighting at home, 26% said they mainly used "incandescent bulbs" whereas 7% that they used tube lights and bulbs somewhat equally. This shows a drastic change in bulb type in thirteen years. The same change can be supposed until now in 19 years with the market trend of LED light that claims more power efficient than fluorescent bulbs. This also shows that user behavior is fairly shifted towards change in technology due to its energy saving factor.

1.3 Rebound Effect

Rebound effect is defined as the increase in the utilization of energy via energy efficient appliances and products because of their reduced operating costs thereby diminishing the energy savings accomplished [12]. It can be concluded that Rebound Effect is related to user's tendency to utilize more energy because of economic profit achieved from the improvement in energy efficiency [13]. Thus Rebound Effect is the change in occupant behavior regarding energy efficiency and can be related to variations in occupant behavior. It is found to be the main reason responsible for the variations in the predicted and actual energy consumption levels in many recent researches. The Rebound Effect can also be termed as “take-back effect” [14].

1.4 Energy consumption and rebound effect

O. Guerra Santin,2013 investigated about the variations in occupant behaviour in relation with characteristics and explored the existance of rebound effect in houses of Netherlands. The results suggested existance of rebound effect on heating behaviour as energy consumption in the houses is affected by hours of use rather than thermostat setting. The ventilation behaviour, on the other hand is found to be affected by the type of ventilation system, type of dwelling and the construction period. The old houses have higher ventilation rates as compared to newly constructed houses. The lower infiltration rate and minimal use of mechanical ventilation systems lead to poor indoor air quality in new houses. Therefore, it can be concluded that accelerated use of heating system and choice for lesser vetilation found to be existed in energy efficient newly constructed houses as compared to old ones. As the household characteristics are different in both types of houses so the differences in behavioral patterns might be associated with household characteristics [8].

K. Ehrhardt-Martinez et al investigated the existance and characteristics of rebound effect and also reviewed possible mitigation strategies to counter the rebound effect. This research compared the technology focused and user centered mitigation strategies to improve energy efficiency. This study concluded that strategies that are based on technology based solutions experience the highest levels olf rebound effects. On the other hand, user focused strategies which combine energy efficiency, conservation and management lead to achieve highest possible energy savings [14].

The major objectives of this study are

1. To determine the impact of energy efficient appliances specifically efficient light fixtures on the occupant or user behavior in residential buildings in Pakistan.
2. To explore the existence of Rebound effect in studying the behavioral patterns.
3. To discuss various strategies to reverse the impact of rebound effect.

2. Methodology

In order to achieve the objectives quoted in the end of the section 1.4, a target group of 5 houses is selected. Within them every space of different activities (living, bedroom, kitchen and washroom) is compared, with a gap of 10 years, regarding the following parameters.

1. Type of lighting fixtures,
2. The number of lighting fixtures,
3. The power of the lighting fixture in wattage
4. The average hourly use per day

The above mentioned parameters are analyzed (by checking the statistical data presented in the tables given in this section) with a gap of 10 years. The data with 10 year gap was calculated by case study method. The houses selected, were studied as case studies and the data was generated by interviewing the residents to know the condition 10 years before and by visual survey to study the present condition. The comparison of these with 10 years gap is analyzed. The analyzed data is reviewed to understand the difference.

3. Results and Discussion

According to the results of following collected data.

Table 1: (a) Table showing types of lighting fixtures a decade before

House #	Types of light Decade BEFORE					Total Types
	Living	Rooms	Kitchen	Washrooms	Others	
A	FL	FL	Incandescent	Incandescent	Incandescent	2
B	FL	FL	FL	FL	Incandescent	2
C	FL	FL	FL	FL	FL	1
D	FL	FL	Incandescent	Incandescent	FL	2
E	FL	FL	FL	Incandescent	Incandescent	2

Table 1: (b) Table showing types of lighting fixtures now

House #	Type of Lights NOW					Total Types
	Living	Rooms	Kitchen	Washrooms	Others	
A	CFL	CFL	CFL	CFL	CFL	1
B	LED	CFL	CFL	CFL	CFL	2
C	LED	LED	LED	CFL	LED	2
D	CFL	CFL	CFL	CFL	LED	2
E	LED	LED	LED	LED	LED	1

The table 1(a and b) are showing different types of lighting fixtures in all the five houses a decade before and now respectively. It is evident that there is no change in types of lighting fixtures a decade before and now as in both scenarios, there are maximum two types of fixtures installed in a house.

Table 2: **(a)** Table showing number of lighting fixtures a decade before

House #	Number of Lights a Decade before					Grand Total
	Living	Rooms	Kitchen	Washrooms	Others	
A	1	1	1	1	1	5
B	2	1	1	1	1	6
C	2	1	1	1	1	6
D	1	1	1	1	1	5
E	1	1	1	1	1	5

Table 2: (b) Table showing number of lighting fixtures a now

House #	Number of Lights in Current scenario					Grand Total
	Living	Rooms	Kitchen	Washrooms	Others	
A	4	2	2	2	1	11
B	6	2	2	1	1	12
C	8	4	3	1	2	18
D	4	2	1	1	2	10
E	8	4	2	2	2	18

The table 2(a and b) are showing number of lighting fixtures in all the five houses a decade before and now respectively. The data given in table shows that there is an increase in number of lighting fixtures in a ten year time period. Same houses have lesser number of lights a decade before and now those houses have more than double number of lights.

Table 3: **(a)** Table showing power in watts of lighting fixtures a decade before

House #	Light Power (No of Lights x watts) a decade before					Total watts
	Living	Room	Kitchen	Washroom	Others	
A	1x40	1x40	1x60	1x100	1x60	300
B	2x40	1x45	1x45	1x45	1x100	315
C	2x40	1x40	1x40	1x40	1x40	240
D	1x40	1x40	1x100	1x60	1x40	280
E	1x40	1x40	1x40	1x100	1x100	320

The table 3(a and b) are showing power of lighting fixtures in watts in all the five houses a decade before and now respectively. The data acquired shows that total power of all the lighting fixtures in any house is generally more a decade before as compared to the total power of all lights in the same house in current scenario except for house C.

Table 3: (b) Table showing power in watts of lighting fixtures now

House #	Light Power (No of Lights x watts) in current scenario					Total watts
	Living	Rooms	Kitchen	Washrooms	Others	
A	4x25	2x25	2x25	2x25	1x25	275
B	6x20	2x22	2x22	1x22	1x22	252
C	6x22	4x18	3x18	1x30	2x18	324
D	4x30	2x30	1x28	1x28	2x18	272
E	6x20	4x20	2x20	2x20	2x20	320

Table 4: (a) Table showing average hour of use of lighting fixtures a decade before

House #	Average hour of use of Light a decade before					Total hours
	Living	Rooms	Kitchen	Washrooms	Others	
A	5	3	1	0.25	0.25	9.5
B	4	4	1	0.25	0.25	9.5
C	5	5	1	0.25	0.25	11.5
D	4.5	3.5	1	0.25	0.25	9.5
E	4.5	4	1	0.25	0.25	10

Table 4: (b) Table showing average hour of use of lighting fixtures now

House #	Average hour of use of Light per day in current scenario					Total hours
	Living	Rooms	Kitchen	Washrooms	Others	
A	6	5	1	0.25	0.25	12.5
B	5	5	1	0.25	0.5	11.75
C	6	6	1	0.25	0.25	13.5
D	7	3	1	0.25	0.5	11.75
E	6	5	1	0.25	0.5	12.75

The table 4(a and b) are showing hour of use of lighting fixtures in all the five houses a decade before and now respectively. It can be deduced from the data in the above tables that hour of use of lighting fixtures have increased now as compared to the use of light hours a decade before. Further the data shows that there is a significant increase in the hours of use of lighting fixtures in all types of houses in current scenario as compared to a decade before.

Electric Power is measured in Kilowatt-Hour (KW/H). For Example if a person consumes 40 Watts CFL daily for 15 hours then

40W (CFL) x 15 Hours = 600 Watt-Hours = 0.6 Kilo Watt Hour

Per Month = 0.6 x 30 days = 18 Kilo Watt Hour

So basically a person consumes 18 units of electricity.

Therefore the number of Units consumed a decade before

House #	Total watts x Total hours	Kilo watt Hour x 30	Total units
A	300 x 9.5	2.85 x 30	85.5
B	315 x 9.5	2.99 x 30	89.7
C	240 x 11.5	2.76 x 30	82.8
D	280 x 9.5	2.66 x 30	79.8
E	320 x 10	3.2 x 30	96

The number of units consumed in current scenario is

House #	Total watts x Total hours	Kilo watt Hour x 30	Total units
A	275 x 12.5	3.43 x 30	103.1
B	252 x 11.75	2.96 x 30	88.8
C	324 x 13.5	4.3 x 30	131.2
D	272 x 11.75	3.1 x 30	95.8
E	320 x 12.75	4.0 x 30	122.4

The data generated from the comparison of types, number, power and hour of use of lighting fixtures before 10 years and now in five residential buildings can be discussed as under.

There were two types of lighting fixtures that were installed in the selected houses ten years before. The same situation prevails nowadays as far as typology of lighting fixtures is concerned. There is not much variety in the type. Only two types have been used in the selected houses. However, the FL and Incandescent bulbs have been used 10 years before in all houses. CFL, LED (Compact Florescent Light, Light Emitting Diode) have been used in all houses nowadays. So there were two types of lighting fixtures ten years before and there are still two types of lighting fixtures nowadays. It means that there is no change in the types in 10 years gap. But there is a significant increase in number of lighting fixtures installed in each house in 10 years gap. There were maximum 6 number of lighting fixtures installed in a house and now the same house utilizes 18 number of lighting fixtures in different rooms. (C, E) It is almost three times more than a decade before. The living rooms of these houses had one or two FL (Fluorescent Light) installed ten years before and now the same living rooms have 4 or 8 CFL, LED (Compact Florescent Light, Light Emitting Diode).

Now if the total power of light is concerned, the power in watts of all lighting fixtures now is equal to or less than total power in watts of lights ten years before. It is for that reason that the energy efficient lighting fixtures are in use now a days. These fixtures (CFL instead of Incandescent Bulbs) utilize lesser energy and are designed to save the energy in building sector [15]. The hours of use per day of lighting fixtures indicates that there is an increase of 15% approximately in average hours of use per day of these lighting fixtures nowadays as compared to their hours of use per day a decade before. As these modern lighting energy efficient fixtures conserve energy so their use has been increased in recent years. This parameter discussed is related to occupant behavior. The major findings of the study are as follows:-

1. The typology of lighting fixtures changed from ordinary to energy efficient lighting in the ten year gap in residential buildings. However, two types were being used in whole building from the ordinary lighting fixtures 10 years before and two energy efficient types are being used nowadays in the whole building.
2. The number of lighting fixtures increased in the 10 years gap in every space of the building.
3. The total power of the lighting fixtures used in the buildings reduced in the gap of 10 years. (showing the energy savings).
4. The average number of hours of usage of the lighting fixtures increased in the gap of 10 years. (showing the careless use of these lighting fixtures by users :- Rebound Effect).

The 4th point of the findings show the presence of rebound effect. It is correct to conclude now that rebound effect has been observed when the lighting fixtures has been shifted from florescent light to modern LEDs.

The lighting fixtures designed for the purpose of only achieving energy conservation causes highest rebound effect and it is suggested to incorporate user based strategies. It is also very important to create awareness among people.

4. Conclusion

According to the analysis, with the advent of energy savers bulbs their number of quantity in each space is increased, in the same way their hourly use is also increased which shows that it is the user behavior which is not letting the positive impact of energy efficiency appliances grow and resulting increment.

The results could have been different if the same numbers of lighting fixture have been used for almost same number of hours as main aim behind the production of energy saving fixture was this but unfortunately it is taken for granted. Now the user is more concerned about their comfort rather than energy saving, as number of hours is increased with number of lighting fixtures.

The user is taking it as indirect rebound effect while thinking that they are getting benefit of more hours and more number of lights within the premises with approximately same cost although direct rebound effect is simultaneously causing environmental degradation and failing to achieve the goal of reducing amount of energy use in the building sector.

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