Advances in Environmental Biology, 9(1) Special 2015, Pages: 6-11

AENSI Journals

Advances in Environmental Biology

ISSN-1995-0756 EISSN-1998-1066

Journal home page: http://www.aensiweb.com/AEB/

Reducing Home Energy Usage based on TRIZ Concept

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ARTICLE INFO

Article history:
Received 25 November 2014
Received in revised form
26 December 2014
Accepted 1 January 2015
Available online 10 January 2015

Keywords:
TRIZ, engineering parameters, energy usage

ABSTRACT

The increasing cost of energy especially with the recent electricity tariff hike in Malaysia has made home owners to be mindful of ways to reduce energy consumption. There are many ways to cut energy consumption at home, fundamentally they can be grouped into two types of approach namely technological and behavioural approach. Both approaches are not easy to implement as the technological one requires replacement of old devices and the behavioural one requires change of lifestyle. In view of this, this research work attempts to apply the theory of inventive problem-solving, TRIZ to solve the problem of increasing consumption of electricity at home. The aim of this research is to derive potential conceptual solutions to help home owners to reduce their energy consumption. The reduction in energy used will also contribute to cost-saving for household and the reduction of carbon footprint.

To Cite This Article: Siti Azfanizam Ahmad, Mei Choo Ang, Kok Weng Ng, Amelia Natasya Abdul Wahab., Reducing Home Energy Usage based on TRIZ Concept. ***Adv. Environ. Biol., 9(1),*** *6-11, 2015*

INTRODUCTION

For years, energy management has become a main concern in large buildings, and offices which consume large amount of electricity. However, recent trends of increasing rate of electricity and cost of energy [1] has made home owners to become more aware and mull about the idea of reducing energy consumption in their home. The effort to reduce home electricity consumption will not only reduce the household expenditure but also contribute directly to reduction of carbon footprint as Malaysia is deeply dependent on non-renewable energy source [1, 2]. Hence, there is an increasing need for people to look into ways of reducing home energy usage or consumption without spending too much. From the literature, a huge number of ways and methods were proposed and introduced to enable people to cut down on energy usage. These proposed ways and approaches to cut down energy usages ranges from introduction of energy saver appliances to the use of stand-by mode features including local home automation technologies [3]. However, the success of reduction in home energy usage is not only limited to using technological-based approaches but also dependent on the behavioral-based approaches. Research has shown that the success of reducing home energy usage via technological-based approaches can be thwarted by direct rebound effect or take back effect due to the change of behaviour. This is because users may think that since his appliances are energy saving types or are automated to save energy, he may increase the demand for energy services (heating, refrigeration, lighting, etc.) by raising thermostat lower when it is summer, procure more appliances or operate them more frequently (take back effect).

Minimizing the gap of required energy consumption and final energy consumption brings to the energy saving [4]. Current levels of energy consumption are high while energy will continue to become more expensive and resulting in budgetary pressure on organizations. Therefore, the various sectors and organizations have taken the approach of creating a system to reduce energy consumption including the introduction of energy saver appliances and the use of stand-by-mode. Different types of technologies, behavioural practices, explanatory variables and methods are some of the factors that contributed to the energy usage. For instance, the revolution of smart home has been introduced by local home automation industry [3]. In this method, devices and appliances such as lights, refrigerators and televisions have been innovated in order to reduce household energy consumption.

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Furthermore, there is a difference in the rate of energy consumption in some areas [3]. For example, residents who live in the city consume more energy compared to those living in suburban and rural areas. This is because in the city, people are more vulnerable to a variety of electronic gadgets such as smart mobile phones, televisions, computer desktops which use a significant amount of energy for their application, recharging and even in standby mode. Furthermore, household energy consumption increases because of changes in lifestyles. Home occupants also play a role in contributing to the amount of energy usage in household [3]. For instance, energy consumption varies as a function of the number of people in household and the time spent at home each day. In other words, by growing number of occupants in the house, it will increase the energy consumption. By time, there are a number of steps have been taken for energy saving objectives and new technologies have been introduced to the users. For example, in Japan, Energy Consumption Information System (ECOIS) was developed and installed in houses [5]. Furthermore, the adaptive control of home environment (ACHE) was also introduced [3]. This system monitors the environment, observes the actions taken by thermostat and attempt to infer patterns in the environment that predict these actions.

Energy saving measures can be characterized in various ways. Different methods are needed to identify the type of energy used in certain area. The type of energy and the utilization rate is different for each location. According to [6], energy-saving measures are characterized by the domain of energy savings whether it comes from indoor or outdoor activities. Indoor activities are including home heating and cooling, lighting, water heating as well as for cooking and the use of household appliances. Outdoor activities concern mainly transportation by any means, for example, for commuting, shopping, leisure activities, and holidays. With increasing the number of population, transportation has become increasingly important. In Malaysia, one of the top energy intensive sectors is the transportation sector and this sector depends mainly on fossil fuel products (contributing to almost 98% of the sector’s entire consumption [7]. Indoor and outdoor energy savings may have different consequences for people’s quality of life, and consequently, for the acceptability of such measures. Rate of energy consumption in both categories is commonly caused by high energy demand in daily activities.

Meanwhile, the energy demands of a building are influenced by many factors, namely climate of the surrounding, indoor climate, building envelope and last but not least the heating, ventilation system, lighting and also the appliances [8]. The climate of the surrounding can be defined by several parameters such as temperature of the air, moisture, velocity of the wind, pressure, solar radiation, and radiant temperature. On the other hand, indoor climate is supposedly influenced by the method of construction of the building. This involves the form of the building, choice of material, the type, size and shape of windows [8]. Climate change impacts local and regional atmospheric conditions including air quality and thermal conditions. In the case building’s indoor climate, the critical factors are the temperature, level of moisture, supply of fresh air, natural and artificial lighting, sources of internal heat, and how long it is occupied. Good indoor climate shields humans against local air pollution and other serious effects of climate change. [9]. Understanding and considering impacts of indoor climate control on regional air quality and global climate can reduce the negative impacts of building technology on building occupants as well as the entire global environment.

The building envelope is the physical separator between the interior and the exterior environments of a building. The design of a building has a big influence on the energy balance. The building envelope is a key aspect of energy-efficient high performance buildings. Solar gains, air leaks, moisture control and thermal (conduction) losses and gains are all affected by the design and construction of the building envelope [10]. The building envelope and the configuration of spaces within the building also affect the potential to bring daylight into the building and to reduce lighting energy used. Thermal losses and gains through windows alone are usually greater than losses and gains through walls and roofs combined. Apart from energy efficiency, the design and construction of the building envelope has a significant effect on occupant comfort [11]. Even when heating and cooling systems are large enough to make up for poorly insulated or leaky building envelope, interior surface temperatures may be cold or hot, and this affects the radiant temperature of the space. Even when the air temperature and humidity within the space are within acceptable bounds, comfort cannot be achieved if an occupant is surrounded by hot or cold surfaces.

The influence of the energy consumption design is driven by the type of the conditioning system such as heating, cooling and air conditioning. Moreover, type of system (air conditioning system with water and air or only with water), heat recovery system and energy transfer within the building and lighting system and the general appliances influence the household energy balance and cannot be easily separated from each other [8]. Hence, it is vital to consider these parameters at a very initial stage of building planning as adjusting these parameters at later stage might require major changes and would be costly.

As described above, the energy consumption of a building is influenced by a number of factors such as surrounding climate, indoor climate, building envelope and heating and ventilation system. Because of each element is related to each other, reducing the electricity bill while maintaining a modern lifestyle is not an easy task. Thus, TRIZ, a structured problem solving was applied to accommodate people to solve the problem.

The research of TRIZ began in 1946. People from the former Soviet Union's universities, research institutes and companies were organized as a research group whose leader was Altshuller. They analysed nearly 2.5

million patents and form the TRIZ theory system by integrating multiple subjects' principles. TRIZ theory consists of 40 inventive principles (Table 1), 39 engineering parameters (Table 2) and a conflict resolution matrix.

Table 1: The 40 Principles of TRIZ.

1.Segmentation	9.Preliminary anti-action	17.Another dimension	25. Self-service	33. Homogeneity
2. Taking out	10.Preliminary action	18.Mechanical vibration	26. Copying	34. Discarding and recovering
3.Local quality	11.Beforehand cushioning	19. Periodic action	27.Cheap short-lived objects	35.Parameter changes
4.Asymmetry	12. Equipotentiality	20. Continuity of useful action	28.Mechanics substitution	36.Phase transitions
5.Merging	13. "The other way round"	21. Skipping	29.Pneumatics and hydraulics	37.Thermal expansion
6.Universality	14. Spheroidality-Curvature	22.Blessing in disguise	30. Flexible shells and thin film	38.Strong oxidants
7.Russian dolls	15. Dynamics	23. Feedback	31.Porous materials	39.Inert atmosphere
8.Anti-weight	16.Partial or excessive actions	24. Intermediary	32. Colour changes	40. Composite Materials

Table 2: TRIZ 39 Engineering Parameters.

1	Weight of moving object	21	Power
2	Weight of stationary object	22	Loss of Energy
3	Length of moving object	23	Loss of substance
4	Length of stationary object	24	Loss of Information
5	Area of moving object	25	Loss of Time
6	Area of stationary object	26	Quantity of substance/the matter
7	Volume of moving object	27	Reliability
8	Volume of stationary object	28	Measurement accuracy
9	Speed	29	Manufacturing precision
10	Force	30	External harm affects the object
11	Stress or pressure	31	Object-generated harmful factors
12	Shape	32	Ease of manufacture
13	Stability of the object's composition	33	Ease of operation
14	Strength	34	Ease of repair
15	Duration of action by a moving object	35	Adaptability or versatility
16	Duration of action by a stationary object	36	Device complexity
17	Temperature	37	Difficulty of detecting and measuring
18	Illumination intensity	38	Extent of automation
19	Use of energy by moving object	39	Productivity
20	Use of energy by stationary object		

Methodology:

The current situation shows that electricity is common energy source for the household appliances. By increasing the number of electrical appliances due to modern lifestyle, the demands for electricity are also increased. As a result, the electricity bill for household is also high. Therefore, it becomes a conflict for household whether to maintain a modern lifestyle and paying a high bill or undergoing a modest lifestyle but committing to a low electricity bill. To overcome this conflict, TRIZ tools, namely, function analysis, component modelling and contradiction matrix are applied.

As energy usage becomes more acute and expensive, there are many efforts to reduce its usage cost especially in the home. Typical house in this problem refers to a double-storey terrace house for middle income group in Malaysia which usually has with four (4) bedrooms, one (1) kitchen and three (3) washrooms. Function analysis was applied in order to understand the elements of the system and their interactions among them. It also identifies problems with those interactions. The engineering system for this problem refers to energy usage for home. The elements of the engineering system are consists of super system components such as environment, sun, wind, rain, heat, light, natural/energy resources and systems components such as house, user, appliances and energy. The functions between the system components and super system components are illustrated in Table 3. Component modelling was used to illustrate the interaction of the useful/harmful function between the eleven components of the engineering system as shown in Figure 1.

The development of the solutions for this problem will be based on Engineering Contradictions. The Engineering Contradictions are applied for each possible root cause that contribute to high energy cost. The details of the Engineering Contradictions including the improving and worsening features related to each root cause and the recommended inventive principles to solve the respective root cause were determined and are also shown in Table 4.

Table 3: Function analysis of reducing energy usage problem.

Function statement			Analysis
Subject	Action	Object	useful or harmful
Environment	Provides	Sun Natural/ Energy resources Wind Rain	Useful Useful Useful Useful
Natural/ Energy resources	Provides	Energy	Useful
Wind	Provides	Energy	Useful
Rain	Cools	House	Useful
Energy	Works	Appliances	Useful (Insufficient)
Sun	Provides	Heat Light Energy	Useful Useful Useful
Light	Illuminates	House	Useful
Heat	Warms	House	Useful and Harmful
House	Houses	User	Useful
Appliances	Serves	User	Useful
User	Uses	Appliances	Useful

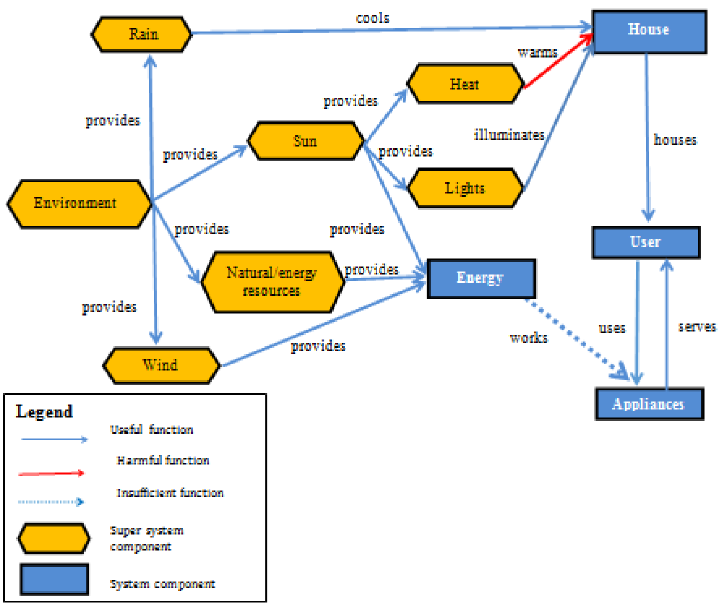

Fig. 1: Component modelling for reducing energy usage problem.

Discussions:

Based on the recommended inventive principles for each root cause, it is obvious that some of the solutions have similar recommended inventive principles. However, recommending a similar inventive principle may not mean the solution is the same but there are some solutions that have similar recommended inventive principles as well as similar solution. This means some of the solutions can solve more than one root cause that contribute to the problem of high energy cost. The details of the potential solutions for solving this problem are illustrated in Table 4.

Conclusions:

TRIZ structured problem solving method has been studied and applied in the reducing energy usage problem. The problem was tackled starting from the surface problem until the ultimate root cause. Instead of using trial and error concept, TRIZ come up with more systematic way to solve problem. Through this way, TRIZ can replace the usual concept of trial and error method and proceed with more organized problem solving method to avoid any repetition. Several TRIZ tools have been utilized to facilitate the problem solving process, including function analysis, component modeling and 40 inventive principles. As a result, the process of the problem solving indeed has become more organized and systematic.

Table 4: Potential solutions to solve the high energy cost.

Problem Statement	Possible root cause Level 1	Possible Root Cause Level 2	Improving Feature (IF), Worsening Feature (WF), Inventive Principle (IP)	Proposed Solution
High Energy Cost	Climate is warm and	Malaysia is located at a tropical climate	IF: Temperature (17) WF: Adaptability(35)	2-open space plan layout with less partition. 27-use coatings; use more fan ceiling/exhaust fan instead of air

	humid	country which experience warm and humid climate.	WF: Device complexity (36) IP: 2-taking out IP: 18-mechanical vibration IP: 27-cheap short/living objects IP: 17-another dimension IP: 16-partial actions	conditioned to reduce energy usage. 17-home orientation to the sunlight; planting trees for shading. Day lighting also reduce energy usage. 16-large size of air conditioned for small room is considered excessive, so use the right size of appliances.
	House design is not energy efficient	Air leaking from the window, doors, roof, wall etc	IF: Temperature (17) WF: Shape (12) WF: Adaptability(35) WF: Device complexity (36) IP: 2-taking out IP: 18-mechanical vibration IP: 27-cheap short/living objects IP: 17-another dimension IP: 16-partial actions IP: 14-spheroidality curvature IP: 22-blessing in disguise	2-open space plan layout with less partition 27-use coatings and seal all the airway to build house envelope. 17-improve house ventilation for the best air circulation. 16- large size of air conditioned for a small room is considered excessive; 14- curvature type of roof is more cool 22-use waste heat to generate electric power
		Home orientation is flooded with sunlight	IF: Temperature (17) IF: illumination intensity(18) WF: Quantity of substance (26) WF: adaptability(35) WF: Device complexity (36) IP: 3-local quality IP: 17-another dimension IP: 30-flexible shells and thin films IP: 39-inert atmosphere IP: 2-taking out IP: 18-mechanical vibration IP: 27-cheap/short living IP: 16-partial actions IP: 1-segmentation IP: 19-periodic action IP: 15-dynamics IP: 6-universality IP: 32-colour changes IP: 13-the other way around	3-roof coatings and glass coatings 17- planting trees at lawn and roof for shading and cool effect 30-use argon in between glasses; use tinted for glass 39- spread water to the roof to give cool effect 2- use open plan layout with less partition 18-use panel solar system 27- use fan at room 16-avoid large air conditioned for a small room 19-clean filter regularly 15-use cross ventilation for windows; 32- light colour for roof and wall; use green or blue colour for glass tinted; colour change to dark when more heats and lighter when less heat 13-use exhaust fan at roof by using solar
		Roof structure absorb heat	IF: Temperature (17) IF: Quantity of substance (the cold and warm air, water) (26) WF: Quantity of substance (26) WF: adaptability(35) WF: Loss of substances (the cold and warm air, water)(23) IP: 3-local quality IP: 17-another dimension IP: 30-flexible shells and thin films IP: 39-inert atmosphere IP: 2-taking out IP: 18-mechanical vibration IP: 27-cheap/short living IP: 6- Universality IP: 24- intermediary	3-roof coatings and glass coatings 17- planting trees at lawn and roof for shading and cool effect 30-use argon in between glasses; use tinted for glass 39- spread water to the roof to give cool effect 2- use open plan layout 18-use panel solar system 27- use fan at room 16-avoid large air conditioned for a small room 19-clean filter regularly 15-use cross ventilation for windows; 32- light colour for roof and wall; use green or blue colour for glass tinted; colour change to dark when more heats and lighter when less heat 13-use exhaust fan at roof by using solar 6- place water sprinkler on the roof. Sprinkle the water on the roof during a hot day. The water spread over the roof and can be collected and reused. 24- use ceiling. The hot air would trap in the space above the ceiling and would not be able to warm the people in the house.
		Wall structure absorb heat	IF: Temperature (17) IF: Quantity of substance (the cold and warm air, water)(26) WF: Quantity of substance (26) WF: Adaptability (35) WF: Loss of substance (23) IP: 3-local quality IP: 17-another dimension IP: 30-flexible shells and thin films IP: 39-inert atmosphere IP: 2-taking out IP: 18-mechanical vibration IP: 27-cheap/short living IP: 24-Intermediary	3- use of bricks ; glass structure; build a door and window for each corner in the house. The cool and warm air can be easily controlled by closing or opening the window and door. 17- planting trees at lawn for cool effect 30-use argon in between glasses; use tinted for glass wall 39- use of argon between glasses. 2- use more open plan layout rather than partition 18-use panel solar system 27- timber wall; paint wall with light colour. 24- use fibre filling between the inner and outer wall.
		House ventilation is poor.	IF: Temperature (17); IF: Quantity of substance (26) WF: Quantity of substance (26) WF: Adaptability(35) WF: Device complexity (36) WF: Loss of substance (23) IP: 3-local quality IP: 17-another dimension IP: 30-flexible shells and thin films IP: 39-inert atmosphere IP: 2-taking out IP: 18-mechanical vibration IP: 27-cheap/short living IP: 16-Partial actions IP: 10-prelimanary action	3- use of bricks ; glass structure 17- planting trees at lawn for cool effect 30-use argon in between glasses; use tinted for glass wall 39-use of argon between glasses. 2- use more open plan layout rather than partition 18-use exhaust fan 27- more windows and apply cross ventilation 10--open the windows and doors before the house gets warm due to the sunlight. The bad ventilation increases the warmth. Higher window helps the hot air leaves the room easily. The cool air remains.
		Heating and cooling system is not efficient	IF: Temperature (17) IF: Loss of energy (22) WF: Quantity of substance (26) WF: Adaptability(35) WF: Device complexity (36) IP: 3-local quality IP: 17-another dimension IP: 30-flexible shells and thin films IP: 39-inert atmosphere IP: 2-taking out IP: 18-mechanical vibration IP: 27-cheap/short living IP: 16-partial actions IP: 7-nested doll IP: 25-self service IP: 23-feedback	3- use of bricks ; glass structure; Use vacuum cleaner only when the normal broom fails to give positive output. 17- planting trees at lawn for cool effect ;use of curtain and blind; avoid carpeting 30-use argon in between glasses; use tinted for glass wall 39- use of argon between glasses. 2- use more open plan layout rather than partition 18-use exhaust fan 27- more windows and apply cross ventilation

ACKNOWLEDGEMENT

The authors would like to thank Universiti Putra Malaysia and Universiti Kebangsaan Malaysia for sponsoring this research by using the funding of the research project GP-IPM/2013/9421800 and FRGS/2/2013/TK01/UKM/02/4.

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