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Building an Energy Efficiency System for Residential Households in the Context of Quantitative Feedback

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Abstract: The way in which households consumed electricity largely influences the total amount of energy used. This paper uses questionnaires to obtain information on the daily electricity consumption behavior of 1,140 households. A comprehensive analysis was used to determine the residential electricity consumption pattern. The study showed that, the traditional residential household electricity consumption patten has some effect on the energy saving strategies, however, it did not provide any scientific or rational information loop system overall. The quantitative feedback platform can be used to improve the level of communication among the residents regarding the electric consumption pattern, and to continuously strengthen residents' awareness of energy saving. In addition, by combining traditional energy saving strategies with the scientific, and systematic residential household electricity energy saving system as a new idea for reducing end-use energy consumption will be useful and may also help in achieving the goal of energy saving subsequently emission reduction.

Keywords: Household electricity consumption; End-use energy consumption; Quantitative feedback; Information loops

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1. Introduction

According to statistical analysis, the total electricity consumption of the country in the year 2021 was 8.31 trillion kilowatt-hours, of which 1.17 trillion kilowatt-hours (kWh), or 14.1%, is used by urban, and rural residents. According to the national standard in 2020, 362.7 million tons of standard coal from the thermal power plants are required to produce one kWh of electricity supply, meaning that around
362.7 million tons of standard coal are required to produce 1.17 trillion kWh of electricity, which may result in the emission of 976 million tons of carbon dioxide (CO) gas. Therefore, residential household electricity consumption is closely associated with the energy saving and emission reduction.

The household electricity consumption ranks in the second position, with the industrial electricity consumption rank in the first position globally [1]. The government can take administrative, and economic measurements to manage the use of electricity supply by enterprises, however the household electricity consumption pattern among the residents is hard to control by the government, and it is completely relying on the resident's awareness on energy conservation. Therefore, it is important to establish an energy-saving system for residential household electricity consumption with the joint participation of the government, enterprises, and consumers.

2. Constraints to the construction of an energy-saving system for residential household electricity consumption

Figure 1 showed a model of the energy-saving system for residential household electricity consumption consisting of government, enterprises and consumers.

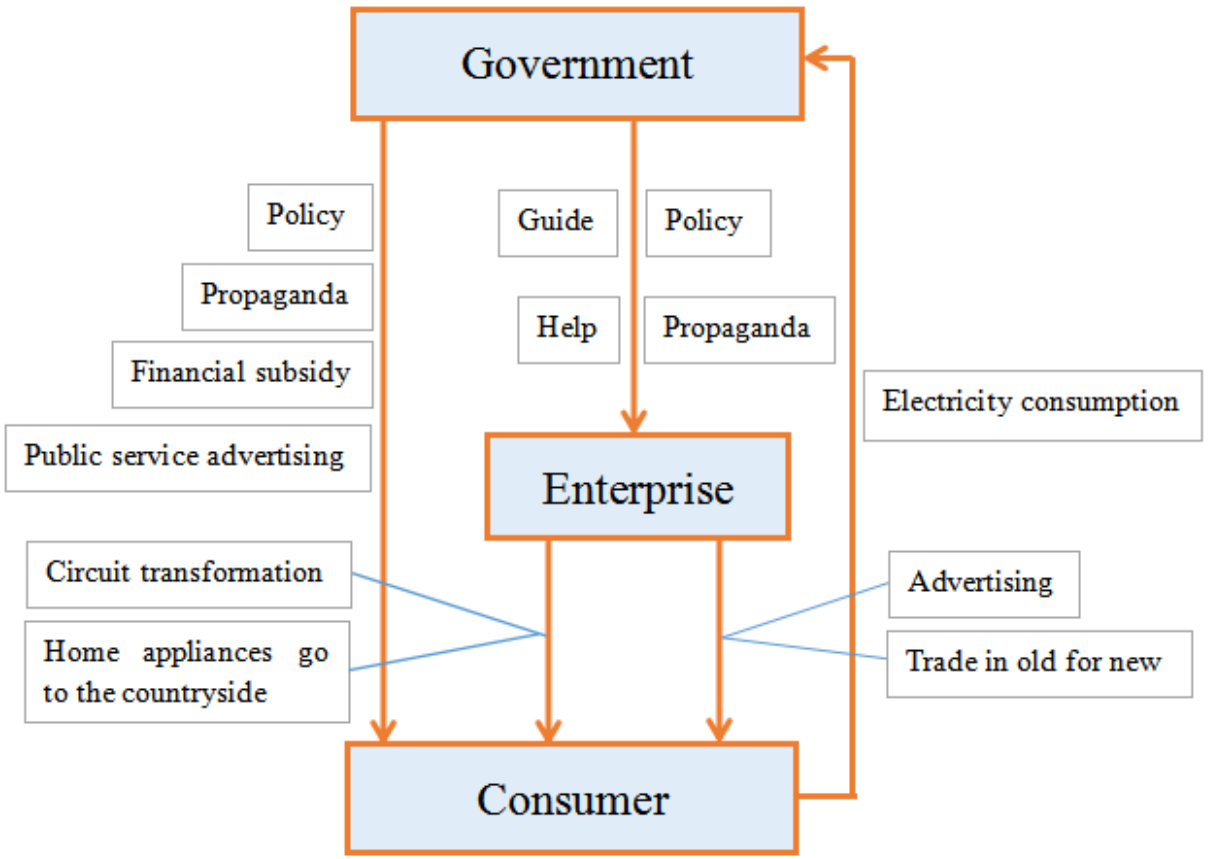

Figure 1. Current patterns of residential household electricity consumption

Current household electricity consumption pattern is mainly guided by the government, and enterprises through campaigns, and financial subsidies, however there are certain constraints as listed below.

Firstly, when it comes to campaigns, and cultivating awareness of energy conservation among residents, their acceptance of the information as the audience varies from a person to another person. The current methods of communication, is mainly through the television, radio, internet, and posters, it is a one-way communication, therefore it is uncertain on audience feedbacks, and acceptance of the given information. At the same time, there is a lack of effective communication within the consumers regarding the energy-saving and non-energy-saving behavior.

Secondly, centralizing the retrofitting of household electrical wiring can ease the residents to disconnect appliances that are not in use, thus facilitating the implementation of energy saving behaviors. However, such retrofitting incurs additional costs for residents, which may not be suitable, or accepted by all the households.

Thirdly, energy efficient appliances are becoming more popular among the consumers, examples are energy saving lamps and solar water heaters. However, for consumers, the new energy efficient products are expensive, unstable and they do not have a good market reputation. Without a good performance and quality guarantees of the energy efficient products, it is difficult to encourage the consumers to purchase

the products even with the government subsidies, and policy support. Therefore, campaigns of energy efficient appliances need to be more strengthened, and the energy efficient products have to be modified, and upgraded as the current energy efficient products do not show much different in the term of energy saving.

Fourth, the existing energy efficiency system is lacking in the term of communication, and integration of the big data with the network platforms, which can result in the lack or missing of information. The greater, the difference between the information may reduce the satisfaction level of the result.

Fifth, the current implementation of a residential tariff system is the main path to guide the residents to conserve electricity, however, its implementation is shown to encounter many constrains, and limitation. Examples are, problems in the meter settlement between co-users, and collective-user, problems with the card-type meters where it does not have segmental billing functions, difficult to read meters for multiple users at the same time when using manual meter reading card, and lastly the electric bill payment system is not user friendly which bring inconvenience to the majority of the residents [2].

3. Reasons for the lack of awareness of energy saving in residential households

Cultivating awareness of energy conservation is the key to develop an energy-saving system for resident's household electricity consumption. At present, residents' awareness of electricity saving is relatively weak for the following reasons.

Firstly, residents' knowledge on household energy saving is still low. Variation in the number of people living in a household, the levels of economic development of the household based on the graphical location, and the age group of the residents contributed to the differences in the pattern of household electricity consumption, thus limiting the effectiveness of the implementation of the tariff policy.

Secondly, there is a misconception between energy efficient appliances, and ordinary appliances. There are a lot of energy efficient appliances available in the market, however, it failed to encourage consumers to purchase the products because of lacking in the performance, quality, and price. Most of the social media which are responsible for publicity energy efficient appliances, is only showing advertisements specific to certain manufacturer or brand, rather than covering all energy efficient appliances which are available in the market.

Finally, the lack of external support in organizing awareness of energy efficiency among residents also contributed to the low knowledge on the energy saving among the residents. Consumer habits, or culture is an important factor in deciding the success of the saving energy system in the home [3]. However, the awareness, and campaign are still lacking up to date, and consumers still having difficulty in distinguishing the energy saving symbols on the household appliances or unable to integrate the importance of energy saving in their daily lifestyle.

Certain groups of people which have an enthusiasm for environmental protection failed to share their knowledge or ideas on energy saving due the lacking in the platform to support them. In summary, different combinations of households, the lack of flexibility in existing policies, the obstruction of the promotion or campaign on energy efficient appliances, the loopholes in the system for cultivating residents awareness on energy conservation, and the lack of a platform for the maintenance of energy conservation enthusiasm has led to the irrational, and shallow knowledge among the residents on electricity saving consumption behavior, which is reflected in the high levels of household electricity consumption. As a result, fossil energy consumption from the thermal power generation cannot be reduced unilaterally.

Therefore, reducing residential household electricity consumption should be given a priority, and residents should reduce producing unnecessary waste in the process of using electricity. It is important to explore, and establish a scientific, and rational system for saving energy in the residential households.

4. Suggested countermeasures for optimizing the energy-saving system of traditional residential household electricity consumption

The construction of an energy saving system for residential households requires the communication between the government, enterprises and residents. Different bodies need to work together or separately in various aspects according to their strengths, and goal to obtain a positive outcome in the residential household electricity energy saving system.

4.1. Flexible tariff policy

The residential tariff reflects the usage of electricity, through the leverage of the price, the mobilizes residents should be encouraged to save, and use the electricity reasonably, and also effectively allocates electrical energy resources to promote the construction of a resource-saving society as an effective measurement to promote universal participation in the energy conservation, and emission reduction [2]. At the same time, the arithmetic simulation shows that the proposed time-of-use electricity pricing method is a practical, feasible, and also conducive method in reducing the peak load on the grid, improving the load curve, enhancing the reliability, and economy of the operation system, and finally, realizing the optimal allocation of resources, and the sustainable development of the power industry [4]. However, this approach is limited by the level of economic development, and the number of individuals in the household. Compared to urban residents, rural residents are more economically disadvantaged, therefore tariff policy can have a greater impact, and be more effective. Moreover, the time-of-use pricing method can only be applied in areas which have one meter for each household. Therefore, it is important to improve, and modified the tariff policy to be more flexible strategy based on the location, and composition of households, thus improving the adaptability, implementation, and impact of the policy among households.

4.2. Hardware support for universal access

In order to increase the contribution of energy efficient appliances to the energy-saving effect on the household electricity consumption, manufacturers should continue to conduct technical research, product testing, and strive to produce high-quality, and high-performance energy efficient products in the market. External incentives showed to have a significant positive impact on the willingness on the residents to purchase green products [5]. At the same time, the government should modify their policies, and support the manufacturers of energy-efficient appliances by giving subsidies to the consumers of energy-efficient appliances, and strengthen the promotion or campaign on energy efficient products, thus encouraging the consumers to purchase energy efficient appliances. Finally, new residents should also be aware of the availability of the energy efficient appliances, and take the initiative to understand, and possibly analyze the advantages of using energy efficient appliances over ordinary appliances, before purchasing it.

The wiring renovation of the residents' home will ease the residence to choose which appliances that need to stay connected or disconnected to the electricity according to their needs. This type of wiring modification is suitable for new home or renovated older homes. Companies, and personnel should focus on promoting energy efficiency products to those who are in the idea of renovating or purchasing new homes, as a path to the extend the wiring retrofit to more households.

4.3. Circulating of information

Messaging, as a way of circulating information on a large scale, has a huge audience, however it is lacking in the information loops. Long waiting time is needed to gain feedback or response from the audience is the main disadvantages of this method. The prolong waiting time hinder the formation of policy or replacement in the content, indirectly leading to increase in total energy usage. Therefore, a sensitive and fast communication platform should be developed to increase, and fasten the interaction between the

audience, and the communicator. Shorter waiting time for the feedback or response from the audiences will help the communicator to make changes or modification of the content faster, thus improving the energy-saving effect.

5.0. Building a multi-loop energy saving system based on a quantitative feedback perspective

The traditional approaches of energy efficiency have long been proposed across different areas of energy efficiency, and have operated in a top-down, permeable, and driven manner. This type of system has a one-way communication, therefore it has low feedback or response from the audience. Hence, it is important to use quantitative mechanisms to create a quick, and effective information loop, to digitalized energy saving actions into visual texts, and to provide feedback to audiences on the positive consequences of energy saving actions, in order to strengthen their awareness of energy saving, and to improve the energy saving system in households.

5.1 Introduction to the concept of quantitative feedback

Quantitative feedback is an effective way of developing a circuit of energy saving information by quantifying the advantage of energy saving pattern in the household, and reflecting them as the resident's consciousness. Quantitative feedback provides a clear, and intuitive picture of the advantage of energy saving actions, thus stimulates the formation of awareness, strengthening the energy saving behavior, and also developing awareness of energy efficiency.

5.2. Quantitative feedback platform

In order to enhance the role of quantitative feedback, and functions in the household energy efficiency system, a corresponding operating platform is necessary to serve as a channel for the collection, and distribution of the large data. The use of smartphones as an operating platform is a promising tool as smartphones are largely used by the general public, and the application on the smartphone can be upgraded, and modified to serve as the saving energy system in residential households.

5.2.1. Articulation areas for quantitative feedback platforms

Most of the software in the market today is developed, and operated by manufacturers for-profit purposes. Although the feedback platform for residential household electricity consumption is based on the quantitative model designed by different commercial software, however, all have software have some similarity, as its main purpose is to strengthen the energy saving system, and reduction in emission reducing the commercial values. Therefore, the operation of this type of platform should mainly rely on government investment or operated by enterprises for the public welfare. Unlike other commercial software, quantitative feedback platforms are less interesting, and more practical, therefore, quantitative feedback platforms should broaden their articulation areas, increase support items, and try to attract potential users from multiple angles.

The quantitative feedback software on energy saving, emission reduction, and also articulation areas should be combined with the existing commercial software, or the practical software which can be are divided into three categories.

Firstly e-commerce: by encouraging the participation of the residents on energy saving by offering some points methods or by linking the software with everyday shopping.

Secondly, public service activities: integrating the quantitative feedback software on energy saving with the software for public service activities, as most of the public service software use quantitative platforms to convert users' actions into numbers in certain units, and convert them into corresponding amounts of donations. This approach fits well with the purpose, and goals of the energy saving software.

Thirdly, e-government: As an important channel for collecting big data on customers' behavior in all aspects of electricity consumption, the quantitative feedback platform has an important role to play in the formulation of government energy efficiency policies. As a direct communication channel between the government and users, the platform should be a bridge between the e-government domain, and energy saving, and emission reduction system.

Fourthly, circuit renovation and the popularization of smart appliances: The quantitative feedback platform aims to increase residents' awareness on energy saving through a convenient quantitative approach, therefore it should be supported by the hardware through circuit renovation, and the popularization of smart appliances to enhance its practicality, and operability.

5.1.1. Quantitative feedback platform functions and information flow

Table 1 shows that the quantitative feedback platform contains ten main functions, including categories such as e-commerce, public interest projects, e-government and information delivery. According to the different states of the participating subjects in each function, there are two main states which are information receiving, and information releasing. The information release, plays an active role in this function, by feeding the received information into the system. According to the number of subjects involved in each function, it is further divided into two categories which are inter-subject communication, and intra-subject communication, to reflect the coverage of different functions. Next, the direction of information transmission is divided into top-down, and bottom-up according to the level of the information releaser, to reflect the construction of information loops.

As shown in **Table 1**, the quantitative feedback platform has seven top-down information output channels, and three feedback channels under the combined effect of the ten functions, forming an effective information loop with maximum coverage. Its inter-subject communication, and intra-subject communication channels which help to promote multi-level, and three-dimensional information communication. The various functions are focused on the daily lives of residents, and ensuring that users can participate in the multiple requests on the same platform, thus increasing the platform's user share.

Table 1. Functions of the quantitative feedback platform

Serial number	Function	Information playback status			Attribute	Information trend
		Government	Enterprise	Consumer		
1	Real time quantization	Receive	Receive	Receive	Inter subject	Top down
2	Bill details	Release	Receive	Receive	Inter subject	Top down
3	Integral lottery	Release	Release	Receive	Inter subject	Top down
4	Energy Saving Publicity	Release	Release	Receive	Inter subject	Top down
5	Public welfare projects	Release	Release	Receive	Inter subject	Top down
6	Discount shopping	Release	Release	Receive	Inter subject	Top down
7	Priority services	Release	Release	Receive	Inter subject	Top down
8	User database	Receive	Partial reception	Release	Inter subject	Bottom up
9	Interactive communication	Receive	Receive	Release	Inside consumers	Bottom up
10	Opinion collection	Receive	Receive	Release	Inter subject	Bottom up

5.1.2. Building a new residential household electricity saving system

The above analysis shows the integrity of the traditional residential household energy efficiency system with the intervention of a quantitative feedback platform. The information loop will help to provide the best effective feedback on residential electricity consumption information in the shortest time, hence shorten the improvement cycle.

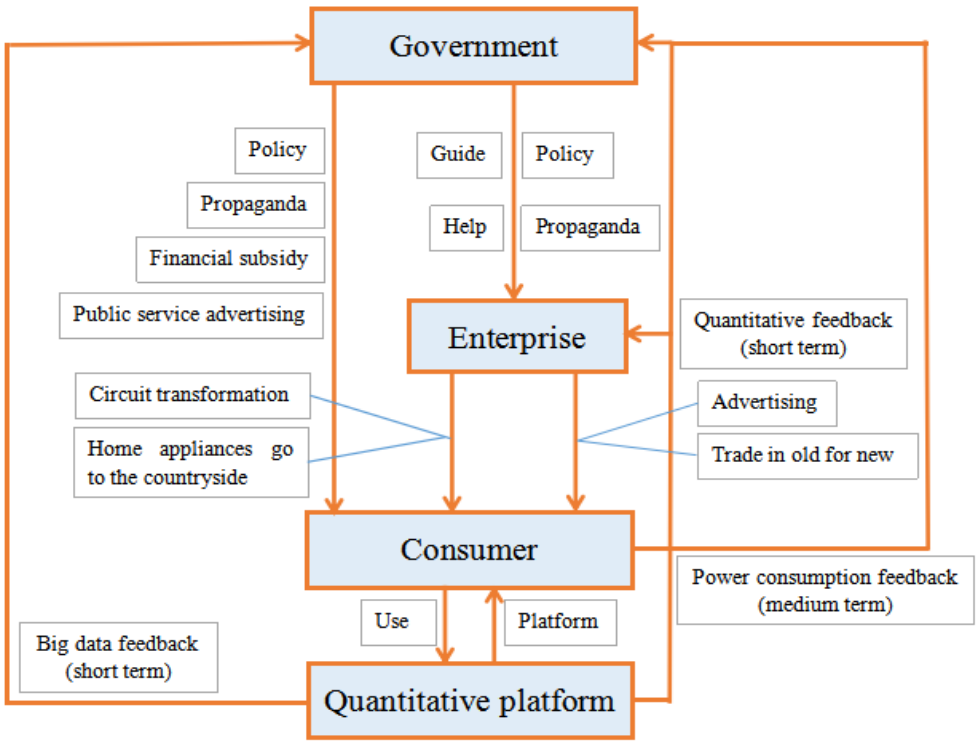

Figure 2. A quantitative perspective on energy saving systems for residential household electricity use

As shown in **Figure 2**, the addition of a quantitative platform to the traditional electricity consumption model effectively complements the original single feedback loop on electricity consumption, combining both government, and enterprises. The quantitative platform can reduce the information feedback cycle, triggering a reduction in the cycle of government policy formulation, production guidance, and enterprise production, and sales plan revision, hence, effectively reducing the energy waste caused by the long waiting cycle. Moreover, the quantitative platform establishes a communication channel within the consumer, and promotes effective, and rapid dissemination of energy saving pattern, and information through social comparison [6]. The use of this platform encounters the lack of flexibility of the tariff policy, and is an effective complement, and sublimation of the household energy efficiency system.

Disclosure statement

The authors declare no conflict of interest.

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