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# Non-market Valuation of Consumer Benefits towards the Assessment of Energy Efficiency Gap

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**Abstract**

One difficulty of carrying out a full cost-benefit analysis in the assessment of energy efficiency investment is the monetization of non-market benefits. This research demonstrates a stated preference approach to non-market valuation of benefits from the consumer perception, by identifying the energy efficiency gap. Through the Contingent Valuation Method (CVM), the Willingness-to-Pay for non-market benefits was evaluated through a face-to-face survey on residents interested in participating in a pilot project of Energy Efficiency Management (EEM) system using Information Communication Technology (ICT) in Hong Kong. In addition, the influences of potential users' demographic and consumption characteristics affecting the WTP of the EEM system are investigated by probit analysis and it was found that *Age*, *Number of occupants*, *Intention* and *Perceived Usefulness* are the dominant factors. This study enables policy makers to enhance the gradual diffusion of energy efficiency technologies through energy management with the real time availability of consumption information.

**Keywords**: Energy Efficiency Gap; Energy Efficiency Management System; Non-market Valuation; Contingent Valuation Method; Ordered Probit Model

## 1. Introduction

Extensive studies have been conducted in the energy efficiency area for enhancing sustainability. The intended benefits of energy efficiency enhancement are found to be reduced by an energy efficiency gap, which arises due to behavioral and structural barriers [1]. Achievement of energy conservation through improving consumption behaviors is considered a cost-effective approach [2]. A research in the



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US shows that much household efficiency improvement efforts were hindered partly because of consumers' low awareness or cognition [3]. It was found by Bhardwaj & Gupta [4] that improving access to easily digested information of power-savings, investment recovery period and carbon emission reduction would lead to significant narrowing of the energy-efficiency gap. Energy Efficiency Management (EEM) systems may be installed in the form of electricity sensing devices coupled with the use of Information Communication Technologies (ICTs), providing real-time consumption information for optimizing electricity usage. In a typical residential situation, the EEM system is connected to household appliances, such as air conditioners, fridge, lighting, etc. It can transfer the electricity consumption data to cloud-based servers, which may be used for power use benchmarking. Real-time dissemination of data from the EEM system enables users to understand their actual electricity consumption versus time and also provides practical bill information for them to improve their consumption behaviors for achieving energy and hence cost savings (Fig. 1).

Energy efficiency plays a significant role in environmental protection consciousness. An EEM system is designed to improve end-user's energy usage and enhance consumers' environmental awareness. As shown in Fig.1, with the availability of new ICT, consumers can check their almost real-time consumption levels in their community and can even participate in a reward scheme for energy saving, which helps consumers to attach a high priority to energy efficiency and environmental performance. With the trend towards developing smart city infrastructures and environmental sustainability, such systems have been developed and spread to economize energy consumption in recent years [5].

Any energy efficiency management system is supposed to yield benefits for the end-users as well as their power supply companies, for the betterment of the environment with concomitant carbon emission reduction. For the power companies, a rationalized demand pattern will avoid overloading their generating capacities and enhance their image in terms of corporate social responsibilities. For the users, the availability of real time consumption information enables their behavioral modification. Nevertheless, investment in an EEM system may represent a hefty amount, which needs to be justified with sound rationale. Hence, a scientific evaluation of the EEM system benefits is necessary for carrying out an economic appraisal.

From the literature, the values of energy-saving and carbon emission reduction can be evaluated with the acquisition of electricity consumption information from the distribution network monitoring equipment of EEM system. These are well documented in published governmental documents [6–8]. However, the evaluation of non-market benefits being perceived by the end-users is only identified with a fuzzy remark, included with a statement or even worse, neglected [9]. To fill this knowledge gap, this study aims at developing a scientific approach for the economic valuation of users' non-market benefits associated with an EEM system undergoing a pilot study in Hong Kong, using the proven method of Contingent Valuation based on data collected from a face-to-face survey with over 400 public housing residents.

## 2. Literature review

Energy efficiency is determined by technologies and end-users' choice [2], under prevailing regulatory constraints. Improvement in consumption behavior and efficiency technologies adoption could substantially conserve energy and yield a profitable investment [10, 11]. However the energy-efficiency gap between predicted profits and actual energy-saving has puzzled decision-makers of related project appraisals for decades due to behavioral and structural barriers [1]. Past energy efficiency investments for improving energy consumption with various technologies often did not achieve the desired economic benefits [12]. Users' choice can be modified through price changing and information disclosure, which are subject to public policies such as tax incentives [2]. General international practices include Time-of-Use (ToU) pricing policy and the adoption of ICT in the energy management [8]. A lack of understanding of the implications of energy use often affects the users' choice [3]. End-users may tend to stick to their energy consumption behavior if little information on their usage pattern is provided. Bridging this shortfall of understanding can help to create early markets for energy-efficient technologies [13].

New energy management practices with upgraded technologies can usually improve efficiency and provide information on energy flows and potential savings as a cost-effective approach to justify investment [14]. EEM system is one such technology proving real-time consumption information to help energy conservation. ICTs can generate significant improvements and cost-saving in data collection and transmission, allowing communication with consumers [15]. In an EEM system adopting ICTs, its intelligent capability presents nearly real-time information of electricity-consumption clearly and makes it possible for the consumers to optimize their usage.

Even though an EEM system is supposed to yield energy-saving, shrink consumption bills, and enhance environmental protection, the investment returns need to be made transparent. Sanstad & Howarth indicated that, a cost and benefit analysis is presumed to be the key method of assessing the policies of promoting the adoption of energy efficiency technologies in analysis of energy-efficiency gap arising out of the 'economic' and 'engineering' approaches [16].

From the UK government report [8], the market values of energy saving from the electricity-consumption reduction due to nationwide smart meter installation amounted to £5.24bn, with gross annual reductions in electricity demand merely at 2.8%. And another behavioral research in the US shows that the electricity consumption reduction was around 2% with similar energy management measures [2]. Besides, in some cities, tariff is relatively low, such as Hong Kong, compared with other cities (e.g. London, Sydney and New York) [17], with power consumption accounting for a relatively low proportion of daily expenses. The potential cost-saving of an EEM is unlikely to overcome the behavioral barriers, and the pricing policy (e.g., the existence of ToU for household use) may not have a significant impact on the structural barriers of energy efficiency gap in the low-tariff cities.

Thus, a reasonable logical deduction in the users' benefits of using EEM system should be from other aspects apart from the market values which can be evaluated directly (e.g., power bill reduction). Laitner and Finman [18] indicated that the benefits of energy efficiency measures included 'energy' and 'non-energy' saving. Asensio & Delmas [19] demonstrate that cost-saving need not be the main benefits for the consumers, but that environment and health are the main benefits of energy efficiency management perceived by consumers. Bhardwaj & Gupta [4] stated that individuals' habits, attitudes, perceptions, and awareness of measures would significantly affect the energy efficiency gap. However, the 'non-energy' benefits are difficult to monetize and hence usually excluded from the estimation [20]. This type of perceived non-market benefits has not been quantified till now. A scientific approach for evaluating the non-market benefits of consumers' perception to break down the behavioral barriers of energy efficiency gap is necessary [9], but so far, the literature has been silent on this aspect.

This study intends to help identify the energy efficiency gap with the non-market valuation of end-user's perception of an EEM system, which is different from the market good cases (see Fig. 2). According to a review based on the official public documents (e.g., EU's Joint Research Centre in 2012 [6], US' Electric Power Research Institute in 2010 [7], and UK's Department for Business, Energy & Industrial Strategy in 2016 [8]), the non-market benefits of EEM to the end-users can be represented by the availability of major household appliances' electricity consumption information, accurate power consumption billing, the use of new technology, and the perceived contributions to carbon emissions reduction and environment conservation. All these intangible benefits will be evaluated in a pilot EEM project in Hong Kong with the contingent valuation method.

Peripheral factors sub-consciously influence one's decisions and perceptions [2]. The demographic and psychological factors can affect the behavioral tendencies of energy consumption and choice of the users. Estimates of demographic parameters by *Age*, *Gender* and other detailed attribute information (such as ethnic composition, education, socio-economic status, etc.) related to households affect energy consumption behaviors [21]. The relationships between general environmental concern variables and electricity consumption were found by Cramer et al. [22]. Taking those findings as reference, this research is designed to test more specific factors of energy consumption and household demographics to determine the relationships between the non-market valuation of the EEM system and the socioeconomic factors in the pilot project.

This paper focuses on the energy paradox on technology and management of behavioral barriers, subject to policy intervention which is usually beyond the control of the individual end-users and is difficult to overcome with a lengthy waiting period of administrative cognizance [1]. With technology improvement, an EEM system, integrates the concepts of technology and management. The EEM system in this study was implemented as a pilot scheme in Hong Kong with the technologies support of two private companies under a government directive based on a smart city agenda for the territory. To help with the management of energy usage in a high-density district of Hong Kong, this new technology offers real-time information to public housing consumers to improve their consumption behaviors. Survey interviews were carried out during the promotion exercise of this pilot scheme over two weekends in early 2018. Through briefing in the promotion exercise and the face-to-face survey, the interviewees understood the functions of the EEM system better and then their answers were collected in the form of a questionnaire.

## 3. Methodology

### 3.1 Contingent Valuation

As a promotional effort in a pilot scheme implemented by the government, the equipment and installation services of the EEM system were provided free of charge to the users. It is not sure if charges would apply in future large-scale installation, which is a policy issue. As such, the economic valuation based on the stated preference technique draws upon theory and practice in the discipline of Welfare Economics [23]. As an effective and widely used tool of stated preference, Contingent Valuation Method (CVM) is mainly applied for non-market valuation [24]. Therefore, in this study, CVM was chosen as an appropriate economic assessment approach for estimating the users' perceived benefits of non-market goods and services about an EEM system. An ordered probit model (assuming standard normal cumulative distribution) was established to depict the relationships between the Willingness-to-Pay (WTP) and the influencing factors [25]. In the process of deriving the WTP, which is reflective of the benefits as perceived [26] by end-users of the ICT system, an econometric model was built to identify the possible factors affecting the valuation of the EEM system.

Two public housing estates in a new district which was redeveloped from an unused airport site were chosen by the government for implementation of a pilot scheme. The number of households was targeted at 100 (after shortlisting) as determined by the organizer of the pilot scheme. Since this number is less than the necessary sample size (around 400 [27]) for ensuring the validity of the CVM, residents who came along to enquire about the installation were interviewed rather than the actual households which would have the EEM installed in their rental premises. Protection of the willing households' privacy also prevented their identities to be obtained after the promotion exercise. Furthermore, according to the organizer, one of the important criteria of eventual installation would be the physical feasibility of wiring the measurement components without damaging the households' finishing and furniture. As such, physical inspections were scheduled to be carried out by an appointed contractor at a later stage to determine the suitability of installation or otherwise.

### 3.2 Economic valuation

The theoretical approaches for estimating non-market benefits may be categorized into revealed preference methods and stated preference methods. Being different from exploiting the actual market information and market behavior as in the case of revealed preference methods, the stated preference methods take advantage of the behavior reacting to some hypothetical questions as stated in the survey to elicit consumer preferences [24].

This study emphasizes end-users' perceived benefits of the installation of EEM system based on the users' attitudes. Through a literature review and a pilot test, the non-market benefits of this EEM as perceived by the consumers included:1) enabling accurate and real-time consumption payment; 2) its effects on the end-user's lifestyle; 3) better IT services, and 4) externalities such as reductions of greenhouse gas emissions, which benefit the citizens' health and enhance environmental protection. These benefits were described in the questionnaire asking about the willingness to pay for the EEM system.

Apart from asking how much the respondents were willing to pay (or willing to accept) according to a hypothetical scenario [27], a series of questions about consumption behaviors were designed in the questionnaire to identify the influence factors of the value chosen or stated by respondents. The analysis of significant factors and behavior model was based on ordinal probit regression, which can inform the types of suitable government policy interventions on top of technologies and management to narrow the energy efficiency gap.

As shown in Fig. 3, in any new technology investment and management measure implementation, an energy efficiency gap often exists with structural and behavioral barriers. In low tariff cities (such as Hong Kong), it is interesting to find out if implementing an ICT adoption in consumption information acquisition would overcome the behavioral barriers. The manner of pricing policy interventions in terms of structural barriers are beyond the control of end-users but still interdependent with behavioral barriers [1]. The EEM system is a typical energy conservation technology combining new sensor technologies and management measures with the use of ICT. Capturing the potential users' attitudes towards the EEM system, a non-market valuation may be used to estimate the long-neglected non-market benefits of energy efficiency gap. Through the valuation of WTP, the non-market benefits may be evaluated at a preliminary stage of this pilot project implementation to help assess the energy efficiency gap, since an insight can be obtained on the user-perceived value of the benefits and the influencing factors so that necessary interventions may be instituted right at the start when the early stage results are known. Further investigation may be carried out when the residents can actually obtain the saving information (both in terms of bill reduction and carbon emission reduction statistics) from the EEM in the long term.

### 3.3 Mathematical analysis

Contingent valuation is usually used as an econometric valuation method in the environmental area for the non-market goods and services in a hypothetical setting [28].The payment card questioning approach of Contingent Valuation is one of the frequently used survey methods out of a variety of means for determining WTP. It often requires face-to-face personal interviews with the advantage of ensuring moderately low complexity and low interview bias [29]. The interviewer presents a number of prices for the goods or services of the hypothetical scenario [30]. The respondents were asked to choose the appropriate maximum WTP they would bear by choosing a value from the payment cards. The answers would be converted to data for subsequent analysis by a parametric model to derive the mean WTP. Besides, through in-depth analysis of the data to extract useful information, this research also intends to explicate the effects of the general explanatory variables on the conceptual dimension of WTP of the EEM system in the high-density urban environment of Hong Kong.

In the questionnaire, the bid values are not continuous, and lie within a given range. Respondents are supposed to choose the maximum amount of willingness-to-pay in a sequence array of bid values presented in the payment card. The numerical outcome of referendum is considered smaller than the chosen bid value. Due to the internal order, the bid values are designed as ordinal categorical variables, with the corresponding numerical values converted to ordered data. In ordinal regression, the cumulative probabilities represent the probability of an event. The observed probabilities can be calculated with the proportion below the standard normal curve [31].

Taking into account gradual changes in the cumulative probabilities, the (cumulative) ordered probit model is particularly appropriate in this study. The regression coefficient of the ordered probit model is interpreted as the marginal effect, the change of one unit of a continuous variable X can initiate the change of the probability of Y to a given value [32], which is the particular bid value of the maximum willingness to pay in this study.

The regression coefficients are estimated by minimizing the sum of squares between the left and the right side of the regression equation. Suppose that there are $j$ payments, $B_1,...,B_j$ (as shown in Table 2), in accordance with ascending order, as $B_j > B_{j-1}$. When a respondent elicits payment $B_j$, the symbol $Pr$ in equation (1) represents the probability that $B_j$ is chosen in the payment card. And $\Pr\ (choose\ B_j)$ is the probability of a respondent picks the payment of $B_j$, which is the equivalent of the probability that his/her willingness to pay lies between $B_j$ and $B_{j-1}$. With the dependent variables lying within a given range, the general probit model is denoted as follows [30, 33]:

$$\Pr\ (choose\ \ B_j) = \Pr(B_{j-1} < WTP \leq B_j) \tag{1}$$

As depicted in the research of Haab and McConnell [30], the ordered probit model $\Pr(chooseB_j)$ in equation (2) is an analysis of explicit normally distributed latent variables, the responses to the payment card can be specified as willingness-to-pay in a parametric model as $WTP = \ \mu + X$. On the assumption of simplicity, it can be linearized, but results are generalizable to many similar models, if $X\sim\ N(0, \sigma^2)$, then the $\Pr$ can be written [30]:

$$\Pr(choose\ \ B_j) = \frac{1}{\sigma}\int_{(B_{j-1}-\mu)/\sigma}^{(B_j-\mu)/\sigma} \phi(t)dt \tag{2}$$

And the response $L$ can be stated with the log-likelihood function [30]:

$$\ln L = \ \sum_{i=1}^{N} \ln[\ \Phi((B_j(i) - \mu)/\sigma)) - \Phi((B_{j-1}(i) - \mu)/\sigma)] \tag{3}$$

where individual $i$ chooses to pay $B_j(i)$ .And $\Phi((B_j - \mu)/\sigma)$ is the Cumulative Distribution Function (CDF) evaluated at $(B_j - \mu)/\sigma$, with the $\Pr(choose\ \ B_j)$rewritten as $\Phi((B_j(i) - \mu)/\sigma)) - \Phi((B_{j-1}(i) - \mu)/\sigma)$ [30]. When the individual picks a payment bid, equation (3) is a form of an interval model, it estimates $1/\sigma$ as the coefficients on $B_{j-1}$ and $B_j$, and the constant term is$\mu/\sigma$. The Estimated Willing-to-Pay (EWTP) is obtained by dividing the estimate of $\mu/\sigma$ by the estimate of $1/\sigma$.

Through the analysis of SPSS, the setting parameters $\overline{V}$ can be elicited [28, 30]:

$$\overline{V} = \ \sum_{k=1}^{n} \beta_k \overline{M_k} \tag{4}$$

where$\beta_k$ is coefficient on the explanatory variable (e.g., *Gender*, *Age*), $\overline{M_k}$denotes each mean of the $k$explanatory variables. The identifiable and relevant sources in this study are the socio-demographic variables and the attribute levels in the EEM system questionnaire [33].

And the econometric analysis with threshold and the CDF of the model can be indicated as [28]:

$$\Pr(chooseB_j) = \begin{cases} Prob \quad (B_j \leq \ T_j - \overline{V}) & (j = 1); \\ Prob \ ( \ \ T_{j-1} - \overline{V} < B_j \ \ \leq \ T_j - \overline{V} \ ) & (1 < j < N); \\ Prob \quad (B_j \geq \ T_{j-1} - \overline{V}) & (j = N); \end{cases}$$

(5)

where$T_j$ is the threshold parameters demarcating utility difference ranges of the $j$ bid value, and $j = 1, 2, \cdots N$.

The equation can be rewritten as [28, 30]:

$$\Pr(chooseB_j) = \begin{cases} \phi(T_j - \overline{V})(j = 1); \\ \phi(T_j - \ \overline{V}) - \phi(T_{j-1} - \ \overline{V})(1 < j < N); \\ 1 - \sum_{j=1}^{N-1} \phi(T_{j-1} - \overline{V}) \ (j = N); \end{cases}$$

(6)

From the CDF, the cumulative normal distribution is denoted by $\phi(\cdot)$ for the present study [28, 33].

Hence the expected value of WTP can be obtained as [28]:

$$EWTP = \begin{cases} \sum_{j=1}^{N} B_j * \Pr(choose \ \ B_j) \ , \ j \geq 1; \\ 0 \qquad , \ j = 0; \end{cases}$$

(7)

## 4. The Survey

### 4.1 Background

The dichotomy between huge amount of greenhouse gas (GHG) emissions versus the aggravation of energy supply pressure is largely blamed for copious energy consumption in Hong Kong. Due to increasingly serious environmental problems posed by energy consumption, energy efficiency measures have attracted more and more researchers' attention. In 2015, the total GHG emission of

Hong Kong was 41,600 kilotonnes $CO2^e$, with about 90% originating from energy consumption in Hong Kong. Electricity (55%), oil &coal products (28%), and town gas & Liquefied Petroleum (LPG) (17%) are the main conventional fuel types in Hong Kong [34]. Especially electricity is the most important power source and affects every aspect of citizens' daily life. Electrical and Mechanical Services Department (EMSD) reported that the main energy consumption sectors of Hong Kong include residential (21%),commercial (43%), industrial (5%), and Transport (31%) [34]. In recent years, accompanied by the growth of population and increase in the number of households, energy consumption of the residential sector has substantially increased in Hong Kong [34]. Thus, this research is targeted at this particular field of residential energy efficiency enhancement in Hong Kong.

Hong Kong has a sub-tropical climate with distinct seasons with Spring (March to May, 17℃-26℃); Summer (June to August, 26℃-31℃); Autumn (September to November, 19℃-28℃); and Winter (December to February, 12℃-20℃) [35], which dictate the types of household appliances in ordinary households, such as air-cons and fridge. From the report of EMSD, *Air Conditioning* (25%), *Cooking* (24%) and *Hot Water* (18%) were major energy consuming end-uses in the residential sector [34].

Hong Kong uses a mix of fuel sources for electricity generation, aiming at half-production capacity using natural gas (remaining coal and oil) [36]. Renewable energy occupies a low percentage (3-4%), although more nuclear power may be imported from mainland China in the long run [37]. Tariff is relatively low compared with major world cities, and Time-of-Use tariff is not yet by default. There is no carbon tax and the two incumbent utility companies (monopolized by location) are subject to Schemes of Control putting a cap on their profits which are related to their asset values.

The EEM system under study can acquire real-time consumption information of designated household appliances with the technical support of ICT. Facilities with ICT have always been the concern of the public with vehement controversy in other jurisdictions. However, in the case of Hong Kong, information technology usage and penetration are high. For example, 79.5% of all households in Hong Kong had their PCs at home connected to the Internet in 2016. The percentage of persons aged 10 and over having smartphone reached 85.8% [38]. With the high proportion of PC and smartphone ownership, it offers a solid basis for the high penetration of ICT in Hong Kong.

In this pilot scheme in Hong Kong, the EEM system was to be installed in two public housing estates with 13,000 housing units in total. Sensors and plugs were installed in selected willing units. The families living in public housing account for a significant share (44.8%) of the overall domestic households of Hong Kong [39]. Therefore, the sampling results would shed light on the attitudes of almost half the 7.3 million population [40].

## 4.2 Procedures

To ensure end-user obtain a clear understanding of the functions of the EEM system, this survey was carried out when the responsible utility company and telecom operator (for the Wi-Fi installation) carried out their promotion to residents in two public housing estates before the commencement of the pilot scheme. The EEM system to be installed in 2 multi-storey high-density public housing estates would be monitored centrally in that the consumption data would be sent automatically to a district government and the utility company within 12 months after the installation. The participating end-users can also track their real-time consumption information on the EEM data platform, using their smart phones, mobile devices or desk-top computers through the household sensors installation. As mentioned, the direct carbon emission reduction for the environmental sustainability will be evaluated through the total energy-saving data to be obtained during and after the 12-month period. However, the perceived benefits of the users cannot be calculated directly. Hence, a face-to-face survey approach was undertaken (the questionnaire can be found at *https://www.xxxxxxxxxx*, now submitted as e-component for reviewers' convenience), using an ordinal probit model for econometric analysis. The survey was based on the payment card questioning approach for Contingent Valuation [24]. After 3 days of face-to-face survey carried out by 2 trained research assistants at a temporary booth set up in the vicinity of the housing estates whilst the 2 responsible companies were promoting the pilot EEM scheme, 416 valid responses with full answers were collected by 2 interviewers, and the demographics are shown in Table 1. According to Mitchell & Carson [27], the valid sample size 416 can roughly represent all people staying in public housing of Hong Kong [39].

Since a significant number of studies were conducted overseas for low density properties [41, 42], it was known that the domestic electricity consumption patterns, household characteristics, income, domestic appliances holding and the number of occupants would be the main factors affecting the consumption behaviors [43, 44]. Besides, the findings of Romanach et al. [45] show that energy consumption would be influenced by both structural and demographic factors, such as the number of bedrooms and number of people living in the household, type of appliances used in the home, etc. From the literature, a questionnaire with 12 questions (as shown in Table 1, 2, and 3) was designed to investigate the perspectives of families interested in the EEM system and they stay in high-density tall buildings. To avoid respondents' privacy concern, the income question was not included. With the survey being carried out in public housing, the income range is defined in the public domain, which is a predominant eligibility criterion for their occupation [39].

In the contingent valuation question, the respondents were asked to choose the maximum amount they were willing to pay one-time for using the functionalities of the EEM system (except electricity saving) regularly, and six monetary values (including *HK$0, HK$50, HK$100, HK$200, HK$500,* and *HK$1,000*) were listed as the bid values from the result of a pilot test conducted with a small sample (14 Nos.) of public housing residents before the formal survey was carried out. This being a hypothetical question, the answer represents the proxy valuation of the EEM system to users, including (as stated in the question) the availability of each major household appliance's electricity consumption information; accurate information of power consumption and bills at any time; the use of new technology; contribution to reduce carbon emissions and protect the environment. The interviewers emphasized that the implementation of this system would in fact be provided free of charge to them in this pilot installation, but some hypothetical payment methods were informed to them. Before answering the questionnaire, the respondents were introduced on the spot the functions of the system, with the sensors and plugs to be installed in the residential units (a sample set available at the booth) after they signed up for the EEM scheme and be shortlisted (Fig. 4). A follow-up question was asked about the reason if zero was picked as the answer to the WTP question [27] for the explanations of the extreme option of zero result. Their facial expressions and spontaneous reactions also enhance the reliability of results obtained, which is an advantage of this auto-reflective data collection approach.

## 5. Results and Discussion

### 5.1 Willingness-to-Pay

As shown in Table 1, middle-aged housewives occupy a significant proportion of respondents with great effects on household electricity consumption. From the valid 416 samples, the results female (63.5%), aged between 31-60 (52.9%), and with secondary education (50.7%) basically accorded with demographic characteristics of Hong Kong [46]. And most of the families have 2- 4 members (77.2%), which is correlated with the average household size of public housing [39]. The results of the survey are representative of the households in the public housing of Hong Kong. In Table 3, 70.2% responses hold the idea that the electricity bills do not affect their other daily expenses (comparing with family income), which remain consistent with the utility company's report about the low tariff in Hong Kong [17]. Another 66.8% of the respondents considered that the initiative of environmental protection affects their daily life, and 76.4% of the responses would agree with a greater need for energy efficiency management if electricity tariff were higher. With the Likert scale as presented in the questionnaire, the mean scores of Q3-the willingness to try new technology (*IT adoption*); Q4-the willingness to improve the electricity consumption behaviors for energy saving (*Intention*); Q5-the extent of improvement to electricity consumption habits (*Usefulness*); and Q6-the impacts of occupants' cooperation on energy saving (*Occupants' cooperation*) all remain above 3.0 within the range of 0 ~ 5 (0 = *Completely No*, 5 = *Extremely Yes*).These reflect the interviewees' positive and optimistic attitudes and environmental protection consciousness in Hong Kong.

Table 2 shows the answers for the WTP and Table 3 shows the descriptive statistical results of all independent variables. As shown in Table 4, after ordinal regression analysis, 4 independent variables have significance levels at 0.001 (*Age*), 0.034 (*Number of occupants*), 0.046 (*Intention*) and lower than 0.001 (*Usefulness*), which are lower than the chosen significance level (0.05). According to the ordered probit model as demonstrated in Equation 7, the EWTP equals HK$161.04, and when multiplied by Hong Kong's public housing population (44.8% of 7.3 million people), the expected non-market benefits would be HK$526.66 million (about US$67.52 million[1]) if the government engages in gradual diffusion of the EEM system and extend the system installation to the whole of Hong Kong's public housing in the foreseeable future.

As to the significant influencing factors, *Age*, *Number of occupants*, *Intention* and *Usefulness* are related to the bid. The coefficient of *Age* is negative, and the coefficients of *Number of occupants*, *Intention* and *Usefulness* are positive. Other factors do not appear to be related to the bid. Hence, *Age*, *Number of occupants*, *Intention* and *Usefulness* are identified as the statistically significant explanatory

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[1] Exchange rate: US$1 = approx.. HK$7.8

variables for non-market EEM system benefits as perceived by the potential users in the context of this pilot scheme in Hong Kong.

5.2 Influential Factors

The result of this research suggests that the WTP of EEM system is affected by a number of socio-economic characteristics of the occupants in Hong Kong public housing. From the analysis of significant explanatory variable in Table 4, *Age* has a negative regression coefficient (-0.212), which shows that the younger generation values the EEM system more. In Fig. 5, the bidding values of respondents aged *19-30* were higher. In Hong Kong, when analyzed by age groups, the percentage of persons aged 65 and over who had knowledge of personal computers (PC) was just 34.5%, and persons aged 65 and over had the lowest rate of having smartphones, at 42.9%. But at the same time, persons aged *15-64* had higher rates of having smartphone or knowledge of using PC, ranging from 85.7.9% to 99.8% [38]. These conditions form the backdrop for the higher acceptance by young people of new ICT-driven energy efficiency systems in Hong Kong. Relatedly, another UK energy policy research shows that decision-making of the elderly can be critical to the success of energy efficiency measures [47]. Since the elderly may find it more difficult to apply new technology, the mode of energy efficiency management for the elderly's absorption is a problem puzzling most governments.

The positive coefficient (0.094) of *Number of occupants* demonstrates that those households which have more occupants have a higher WTP for the EEM system. As shown in Fig. 6, the respondents with a larger *Number of occupants*, 7 or 8, were all willing to pay for the EEM system (the chosen bid values of WTP were all higher than zero). Previous findings show that energy consumption is influenced by the number of bedrooms and number of people living in the household [42, 45]. It has been demonstrated in a number of studies that the total energy consumption is positively related to the *Number of occupants*, and the residents in high occupancy households would have more appliances and higher usage frequency [48]. Especially, the citizens in Hong Kong live in a high-density urban environment, with per-capita living area comparatively small, and more occupants usually mean a higher strain to pay energy bills. Thus, they would pay more attention to energy-saving and relevant measures. Their perceived benefits of the EEM system were perceived to be higher.

The third significant explanatory variable, *Intention* with the positive coefficient 0.071, indicates that the willingness to improve consumption behaviors for energy saving has a significant impact on the valuation of the EEM system. As shown in Fig. 7, *improvement* and *active improvement* form the majority in the response of *willingness to improve the electricity consumption behaviors for energy saving*, which suggests a positive attitude of the bulk of the population of Hong Kong public housing. The Theory of Reasoned Action (TRA) [49] indicates that personality, values, social psychology of attitudes will exert significant intellectual effects on the consequences. The respondents were required to assume themselves as potential users when they made decision on the WTP. The respondents' elicitation of WTP can be regarded as their predicted action based on the hypothetical scenario described to them. The responses with higher intentions level to improve consumption behaviors are dominant in the bidding of WTP (Fig. 7). This empirical relationship between the *Intention* (willingness for energy-saving) and the WTP is in good accordance with TRA. Thus, enhancing consumers' awareness of energy conservation and the environment should be an important strategy for policy intervention.

The fourth is *Usefulness*, and the coefficient is also positive (0.157), indicating that the awareness of real-time consumption information has a positive correlation with the benefits perceived by the potential users, which is depicted in Fig. 8. The higher level perceived of the usefulness of the real-time consumption information, the more the consumers were willing to pay for the EEM system. The mean score of *Usefulness* reached 3.28, which indicates that the potential users' attitude to the real-time information system is higher than the indifference level, and the availability of real-time consumption information is important for consumers in Hong Kong.

The survey results indicate the potential participating families' perspectives towards the EEM system in Hong Kong. Younger households with more occupants, a higher recognition of the energy conservation need, and a higher appreciation of the usefulness of real time consumption information would have a relatively higher likelihood to enjoy more non-market benefits perceived. All the four factors provide good insights for implementing intervention measures to overcome the behavioral barriers of the energy efficiency enhancement. Thus, the promotional efforts and the publicity of EEM should be stepped up to increase citizens' awareness for energy conservation.

## 6. Conclusion

This research provides insights into the energy-efficiency gap vis-a-vis technology adoption and management practices. The EEM system represents an efficient technology of new ICT being adopted in energy management. It overcomes the behavioral barriers of energy-efficiency gap with real-time information helping to improve energy consumption behavior. With the attribute of both the new technology and management, it is hoped that EEM systems can enhance energy efficiency and help narrow the energy efficiency gap between anticipated economic, social and environmental benefits and actual saving. The market values of energy saving yielded by an EEM system may be estimated in monetary terms directly from bill information, and the non-market benefits evaluated with the CVM as presented in this study. Hence, the total benefits to consumers may be estimated in monetary terms. The non-market valuation of an EEM system from the consumers' perceptive enables the energy efficiency gap to be bridged.

With the objective of evaluating the non-market benefits of consumers, this research has both theoretical significance and practical applications in the economic assessment of EEM system. It has valued the non-market benefits as perceived by the end-users about an EEM system based on the stated preference approach. This is for estimating the non-market values of the energy efficiency measures to help evaluate the energy efficiency gap. The potential users' demographic and social attitudes related to the EEM system have been investigated in this study. An ordered probit model with the significant influencing factors of *Age*, *Number of occupants*, *Intention* and *Usefulness* has been demonstrated for evaluating the non-market benefits of consumers. This research has both theoretical significance and practical applications in the economic assessment of EEM system. With close monitoring of the influential parameters by the policy makers (e.g., through ensuring a well-spread age range and occupation level for the resident participants), the perception of the EEM system may be improved. This provides a basis for further research and appraisal of energy efficiency technology diffusion projects to mitigate against the behavioral barriers of the energy efficiency gap.

The benefits represented by both market and non-market values of an EEM system should be essential components of any alternative appraisal of EEM systems. With the energy efficiency gap quantified, decision-makers may fund the investment of energy-efficiency projects with a higher certainty of returns (both market and non-market benefits). However, the awareness of the need for energy conservation and the digital divide, especially for the elderly, on ICT would raise further concerns.

## ACKNOWLEDGMENT

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## Appendix A

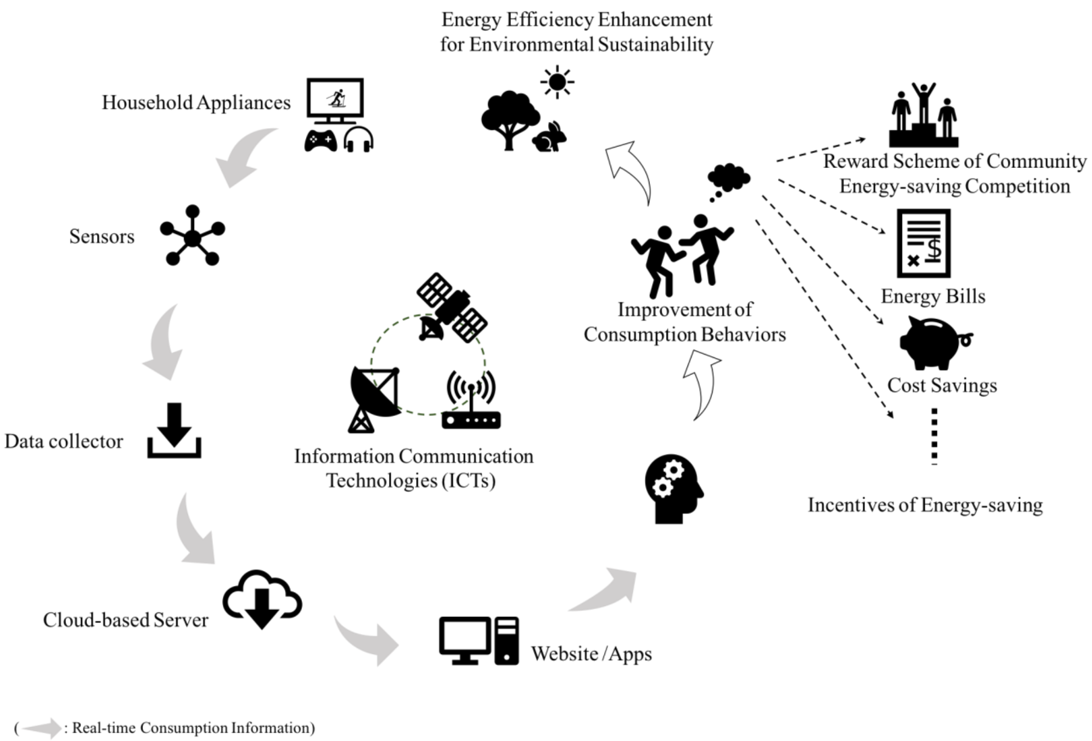


Fig. 1. Overview of a typical EEM system towards energy efficiency enhancement utilizing ICTs

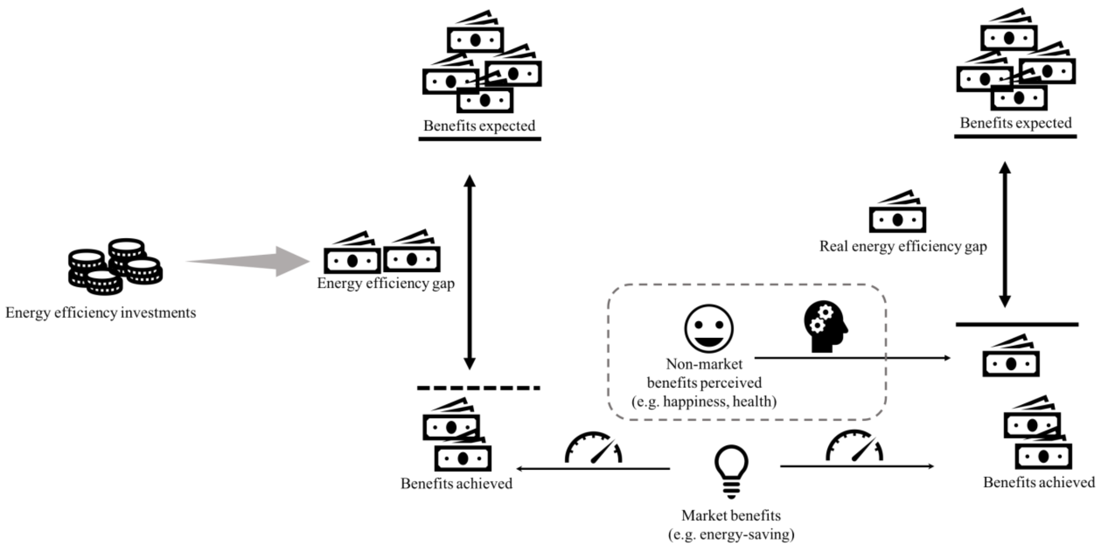


Fig. 2. Assessing the energy efficiency gap with non-market benefits from the consumer perception

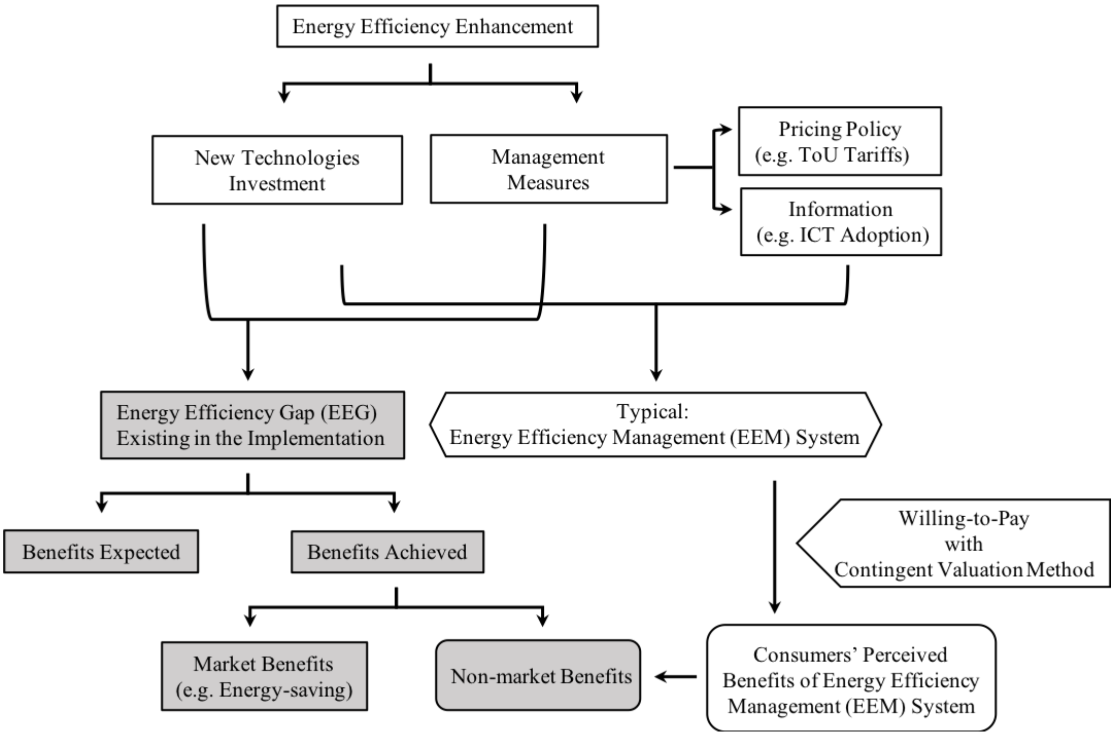


Fig. 3. Framework for assessing energy efficiency gap with non-market benefits valuation in the pilot EEM scheme

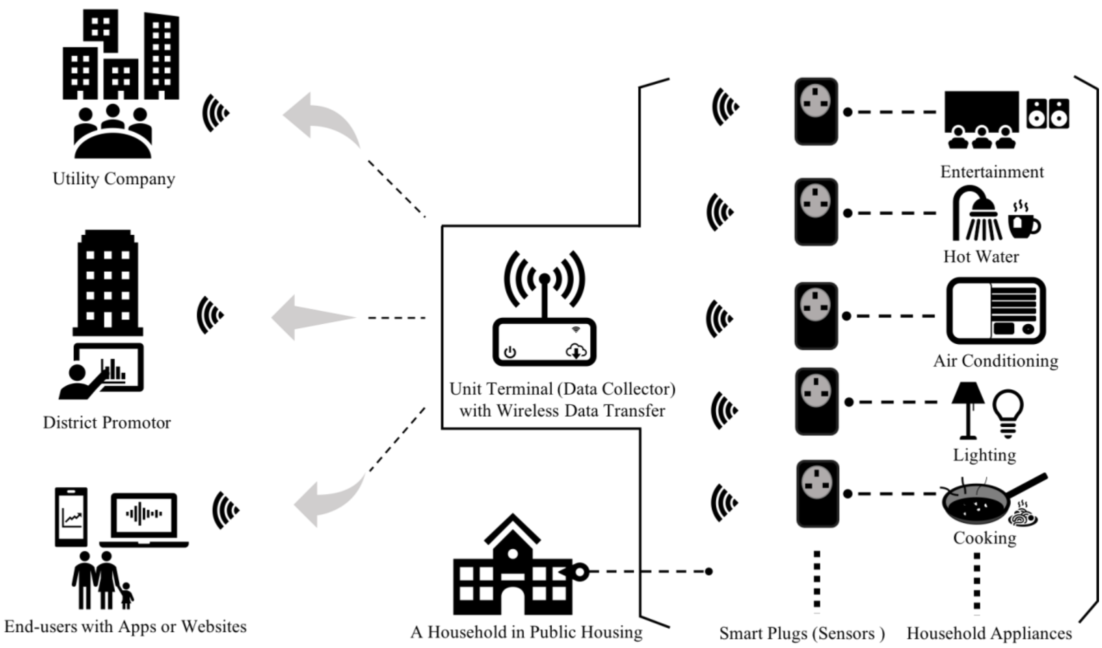


Fig. 4. The pilot EEM scheme in Hong Kong public housing

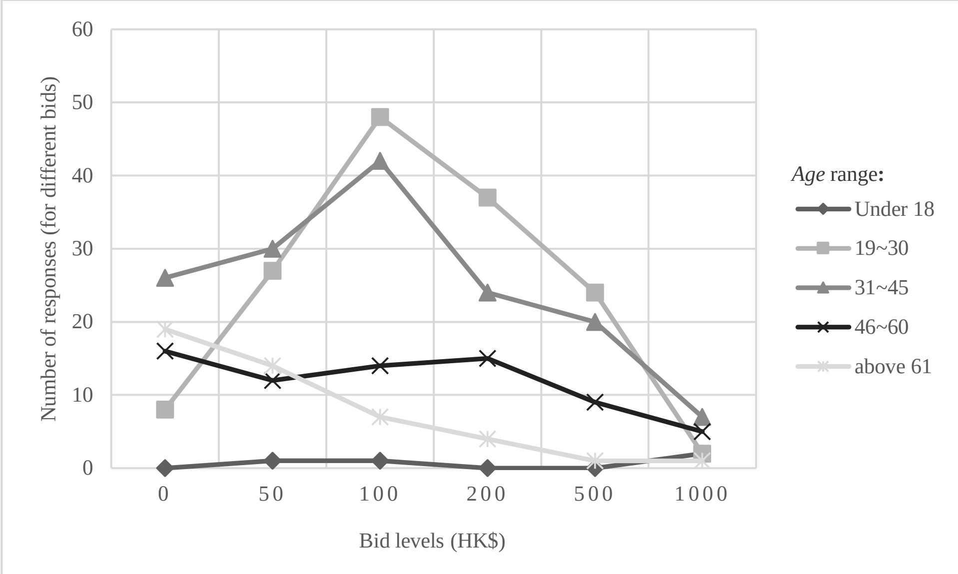


Fig. 5. Interrelation between *Age* range and the maximum Willing-to-Pay

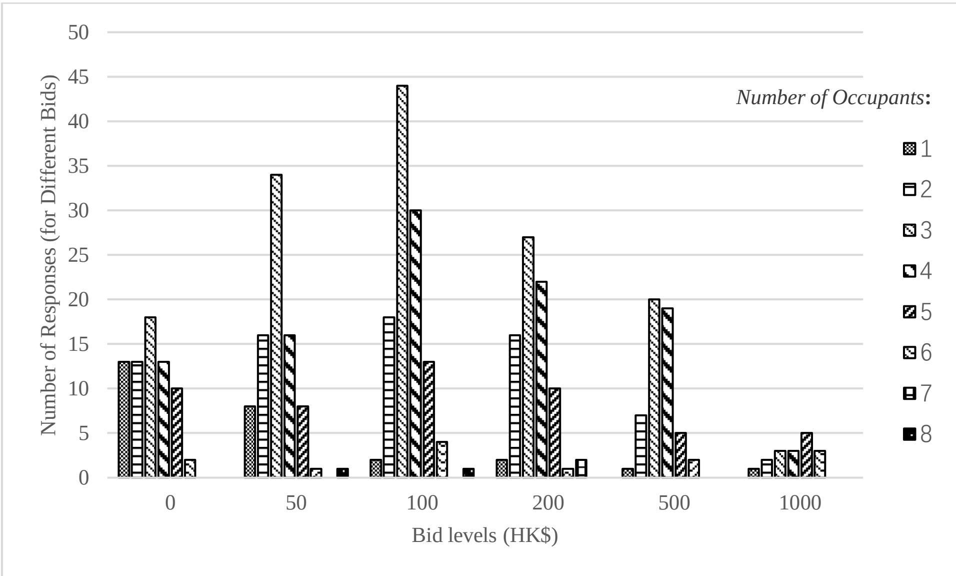


Fig. 6. Interrelation between *Number of Occupants* and the maximum Willing-to-Pay

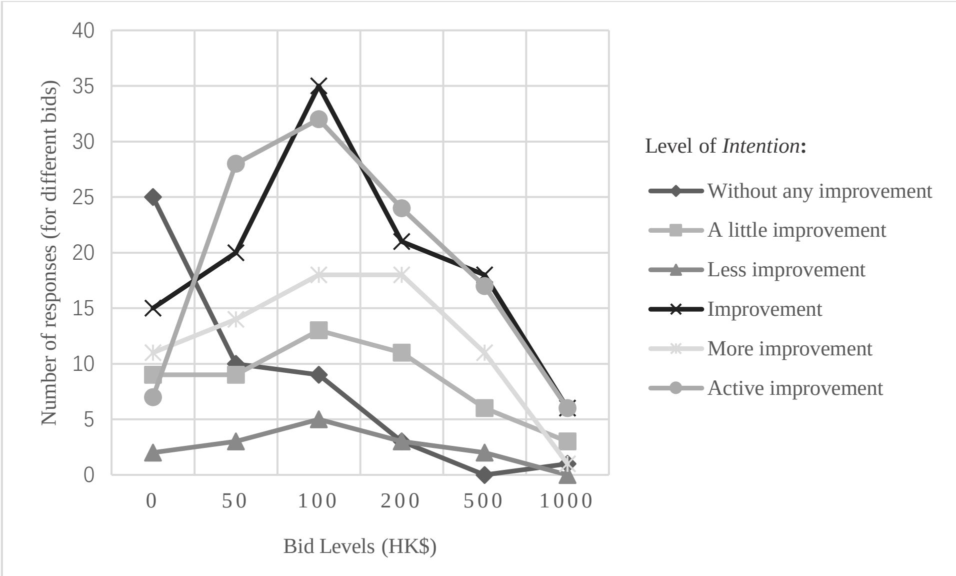


Fig. 7. The level of willingness to improve the electricity consumption behaviors for energy-saving (*Intention*)

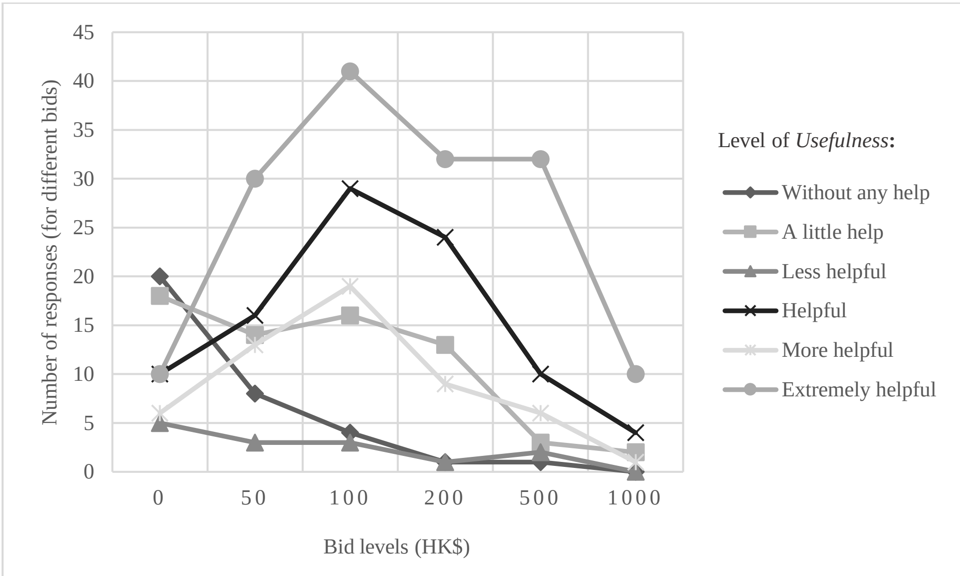


Fig. 8. The level of the real-time information's help to improve the electricity consumption habits to save energy (*Usefulness*)

## Appendix B

**Table 1.** Respondents' demographic profile and co-variates

| Variable | | Frequency | Percent | Description | Mean | Std. Deviation |
|---|---|---|---|---|---|---|
| Gender | Female | 264 | 63.5 | 1 = *female*; 2 = *man* | - | - |
| | man | 152 | 36.5 | | | |
| Age | Under 18 | 4 | 1.0 | 1 = *Under 18;*<br>2 = *19~30;*<br>3 = *31~45;*<br>4 = *46~60;*<br>5 = *above 61;* | 3.02 | 1.022 |
| | 18~30 | 146 | 35.1 | | | |
| | 31~45 | 149 | 35.8 | | | |
| | 46~60 | 71 | 17.1 | | | |
| | Above 60 | 46 | 11.1 | | | |
| Education | Primary education | 37 | 8.90 | 1 = *Primary education;*<br>2 = *Secondary education*;<br>3 = *College or diploma*;<br>4 = *University and above;*<br>5 = *Others.* | 2.55 | 0.950 |
| | Secondary education | 211 | 50.7 | | | |
| | Post-secondary | 69 | 16.6 | | | |
| | University and above | 99 | 23.8 | | | |
| | Others | - | - | | | |
| Number of Occupants | 1 | 27 | 6.5 | - | 3.33 | 1.243 |
| | 2 | 72 | 17.3 | | | |
| | 3 | 146 | 35.1 | | | |
| | 4 | 103 | 24.8 | | | |
| | 5 | 51 | 12.3 | | | |
| | 6 | 13 | 3.1 | | | |
| | 7 | 2 | 0.5 | | | |
| | 8 | 2 | 0.5 | | | |

**Table 2.** Description of dependent variable 'WTP'

| | Bid Values (HK$) | Valid Frequency | Valid Percentage | Threshold Estimate |
|---|---|---|---|---|
| The maximum Willingness-to-Pay one-time to enjoy the services of EEM system (except monetary energy-saving). | 0 | 69 | 16.6 | -0.423 |
| | 50 | 84 | 20.2 | 0.324 |
| | 100 | 112 | 26.9 | 1.091 |
| | 200 | 80 | 19.2 | 1.745 |
| | 500 | 54 | 13.0 | 2.587 |
| | 1000 | 17 | 4.10 | - |
| Overall | total | 416 | 100.0 | - |

**Table 3.** Explanatory variables

| Variable | Description | Frequency | Percent | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Comparing with family income, whether the tariff affect other daily expenses (**Income**) | 0 = *No*; | 292 | 70.2 | - | - |
| | 1 = *Yes*. | 124 | 29.8 | | |
| Whether the initiative of environmental protection affecting life style | 0 = *No*; | 138 | 33.2 | - | - |
| | 1 = *Yes* | 278 | 66.8 | | |
| The level of willingness to try new technology (**IT adoption**) | (0 = *Completely unwilling*;<br>1= *A little willingness*;<br>↕ …<br>5= *Extremely willing.* | - | - | 3.65 | 1.606 |
| The level of willingness to improve the electricity consumption behaviors for energy saving (**Intention**) | 0 = *Without any improvement*;<br>1= *A little improvement*;<br>↕ …<br>5= *Active improvement.* | - | - | 3.10 | 1.683 |
| The level of the real-time information's help to improve the electricity consumption habits to save energy (**Usefulness**) | 0 = *Without any help*;<br>1= *A little help*;<br>↕ …<br>5= *Extremely helpful.* | - | - | 3.28 | 1.719 |
| The level of impacts of occupants' cooperation on energy saving (**Occupants' cooperation**) | 0 = *Completely unaffected*;<br>1= *Influence a little*;<br>↕ …<br>5= *Extremely affect.* | - | - | 3.06 | 1.728 |
| Whether EEM is more useful with higher tariff (**Higher Tariff**) | 1 = *No*; | 69 | 16.6 | 2.60 | 0.757 |
| | 2= *I have no idea*; | 29 | 7.0 | | |
| | 3 = *Yes*. | 318 | 76.4 | | |

**Table 4.** Ordinal regression[1] – estimation of explanatory variables in the model[2]

**Parameter Estimates**

| Variables | Estimate | Std. Error | Wald | Confidence Interval | |
|---|---|---|---|---|---|
| | | | | Lower Bound | Upper Bound |
| Gender | -0.034 | 0.109 | 0.097 | -0.247 | 0.179 |
| Age | -0.212*** | 0.063 | 11.439 | -0.335 | -0.089 |
| Education | -0.041 | 0.065 | 0.399 | -0.167 | 0.086 |
| Number of Occupants | 0.094** | 0.044 | 4.512 | 0.007 | 0.180 |
| Income | 0.164 | 0.119 | 1.889 | -0.070 | 0.398 |
| Green | -0.165* | 0.113 | 2.138 | -0.386 | 0.056 |
| IT adoption | 0.048 | 0.036 | 1.822 | -0.022 | 0.119 |
| Intention | 0.071** | 0.036 | 3.989 | 0.001 | 0.141 |
| Usefulness | 0.157*** | 0.036 | 19.225 | 0.087 | 0.227 |
| Occupants' cooperation | 0.025 | 0.032 | 0.612 | -0.038 | 0.088 |
| Higher tariff | 0.077 | 0.074 | 1.076 | -0.068 | 0.222 |

[1]Link function: Probit.

[2] The significance level of overall model-fitting is lower than 0.001, which suggests that the model fits well.

* Statistically significant at 90% level;

** Statistically significant at 95% level;

*** Statistically significant at 99% level.