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Reducing residential energy consumption through a marketized behavioral intervention: The approach of Household Energy Saving Option (HESO)

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ABSTRACT

Behavioral strategies of occupant energy conservation are essential to counter the effect of growing energy demand. The wide application of occupant energy interventions, such as providing subsidies to promote energy saving, involves continuous financial investments, which has been a particular challenge to subsidy providers, i.e. national energy agencies. Exploring the cost-effective interventions is essential in the case of promoting household energy conservation in the long term. In this study, a promising strategy to lighten the financial burden of energy policy providers - Household Energy Saving Option (HESO) is proposed and validated. HESO is an option-based strategy that offers buyers (i.e. households) an opportunity to earn the reward, depending on whether they can achieve the pre-determined energy saving goal. A conceptual framework of HESO is established, which consists of five elements, namely theoretical foundation (T), integrated interventions (I), market premises (M), energy sustainability (E), and stakeholders (S). To test the effectiveness of HESO on household energy reduction, a preliminary experiment was conducted in 101 households living in Singapore and the results demonstrated that HESO has a positive effect on encouraging home electricity conservation based on the Difference-in-Difference (DID) analysis. Compared to the baseline of household energy consumption, HESO-induced energy reduction was 8.18% and 12.56% when saving goals were set at 5% and 10%, respectively. Possible reasons to explain different effects of HESO on energy reduction have been elaborated, including the effect of positive feedback and re-adjustment of households' energy saving motivation during the transition period. Key determinants of HESO's success have also been discussed, such as management of cash-flow liquidity and design of goal difficulty. HESO shifts costs from energy policy providers to the households who fail to achieve their goals, which significantly improves the cost-efficiency of residential energy reduction strategies. This study contributes to the literature by developing a framework of option-based residential energy saving intervention. The results enlighten a promising and scalable solution by using a marketized intervention for promoting effective energy conservation in households while minimizing the cost burden borne by the city government.

1. Introduction

Building sector has been considered as a key part of global energy consumption. In particular, 27% of the total energy consumption and 17% of the total CO_2 emission were contributed by the building sector [55]. According to Duarte, Raftery, & Schiavon [15], energy usage in buildings would be projected to increase by 32% between 2015 and 2040 worldwide. This is the results of rapid urbanization, industrialization, and the development of smart city [8]. Moreover, residential buildings take up a great amount of energy usage in building sector. In Singapore, residential buildings contribute more than 15% of energy usage with an increase year by year. To address the growing household energy demand, various approaches have been studied [37,27]. Broadly, mitigation strategies can be divided into two categories: technology-based strategies and behavior-based strategies [20]. Technology-based

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strategies are those aiming to reduce inputs for production processes via enhancing resource productivity or to achieve closed-loop material cycles (i.e. substitute unsustainable materials with materials consistent with nature) [72,24]. Behavior-based strategies are those to focus on reducing energy consumption from the demand side, such as changing consumers' energy-related behaviors [72]. As reported, occupants' behaviors contribute to nearly 80% of the variation in energy consumption [35], moreover, behavior-based strategies are more cost-effective as they usually require less initial investment [76]. Therefore, developing effective and cost-efficient behavioral energy strategies to promote residents' energy conservation is vital to reduce global energy consumption.

The behavioral intervention strategies can be broadly classified into antecedent and consequence strategies [2]. Antecedent strategies are those to be introduced before energy behaviors, such as commitment and goal-setting, which hold several distinct advantages over other approaches [4]. First of all, they can prevent problematic behaviors beforehand. This is important not just in the way to eliminate undesired outcomes but also to form an atmosphere where learning can occur. Another strength of antecedent strategies is that they usually result in immediate reactions [4]. Since antecedent interventions are usually tailored to a certain group of households, the process of trial-and-error is saved and desired behaviors can be called for immediately. However, Katzev & Johnson [33] pointed out that a low number of respondents making commitment may have reduced the power of antecedent strategies.

Consequence strategies are those assumed to influence households' energy saving outcomes after the occurrence of the energy behavior by providing a consequence, such as feedback or monetary rewards, based on the outcome of the behavior. For instance, studies from Nolan, Schultz, Cialdini, Goldstein, & Griskevicius [58] and Ferguson, Branscombe, & Reynolds [18] have found that providing comparison information about others' energy usage influenced individual household energy sustainable behaviors. However, the effect of informational feedback strategy implemented in the UK on home energy consumption was reported insubstantial (only 2% reductions in the short term) [9]. Another problem of providing informational feedback and monetary reward is a high cost borne by policy providers. The findings from Abrahamse et al. [2] supported that consistent monetary rebates are necessary to keep participants motivated, which may lead to high fiscal cost for energy policy authorities. Therefore, finding an effective energy intervention with the minimum fiscal cost is critical to reduce household energy consumption.

The aim of this study is to develop an effective and cost-efficient intervention in order to promote building energy saving in residential sector. Specific research objectives include 1) to develop the innovative cost-efficient intervention – Household Energy Saving Option (HESO), which is an option-based intervention that provides participants right but not obligation to obtain reward once they achieve energy saving goal; and 2) to test the effectiveness and cost-efficiency of HESO on household energy saving through a pilot study. This study is the first to explore such an option-based hybrid intervention through the comparative data on the changes in home energy consumption prior and post HESO strategy. The results of this study showed the promising effect of adopting HESO on encouraging households' energy conservation. This research not only contributes to the literature by developing the framework of a theoretically-grounded design of a holistic household electricity saving strategy, but also makes a practical contribution by providing suggestions for energy agencies, such as setting the appropriate ratio of premium to reward from 1:2 to 1:1.5.

The paper is organized as follows. In Section 2, a thorough review of existing literature about household energy saving interventions was conducted. The development of the conceptual framework of HESO was proposed in Section 3. Research methodology and experiment design were presented in Section 4. Results through a comparative analysis of energy reduction of participated households were demonstrated in Section 5. Theories explaining the fluctuation of household energy saving during the experiment period and key determinants of HESO's success were discussed in Section 6, followed by a conclusion in Section 7.

2. Review of previous studies

Three types of household energy saving interventions were reviewed in this study, which were antecedent interventions, consequence intervention, and structural interventions. Among them, antecedent interventions include commitment, goal-setting, and information provision. Examples of consequence interventions are feedback and rewards. Structural interventions refer to the combination of antecedent and consequence interventions, market-based interventions, and interventions integrated with game-like elements.

2.1. Antecedent interventions

1) **Commitment**

Commitment is a promise pledged in oral or written format to adopt energy conservation measurements, which is based on the Theory of Commitment [34]. The theory suggests that people potentially worry about negative implications of attitudinally explicit behaviors, especially when their commitment or perceived responsibility for the behavior is high. Several studies have found that people seem inclined to adhere to their commitments and thus exhibit behavioral change [77,29,34,2,1,59]. For example, a meta-analysis by Lokhorst, Werner, Staats, van Dijk, & Gale [46] showed that commitment-making is effective across different environmental behaviors. Prior studies also provide ideas of underlying mechanisms of the effect of commitment intervention.

Three possible explanations have been proposed in the literature. Firstly, some researchers believe that making a commitment might change individuals' ideas about what they value. If people make a commitment to reduce their daily energy consumption, they must feel the goal, such as mitigating global warming, is important to them. In other words, people will be motivated by the goal set by them and adjust their behaviors to reflect the value they put on the goal [12]. Another explanation states that as long as people believe they make commitment voluntarily, they will persuade themselves that the efforts made to fulfill that commitment are worthwhile [46]. Lastly, the normative mechanism has been used to explain commitment made in public. The pledge to commit to a specified goal can be a personal promise or make it publicly [82]. If people fall away from public commitment, negative social sanctions may be applied to them. It is necessary to note that these three explanations may overlap to a certain extent. Therefore, the ideas of underlying factors explaining the effectiveness of commitment to energy reduction may mutually support each other.

2) **Goal-setting**

Goal-setting in energy reduction involves the development of an action plan designed to motivate and guide a person or group toward a specific energy saving goal. It has been frequently used as an intervention to encourage energy conservation, with goal difficulties ranging from 5% to 20% [5].

Typically, the goal-setting can be in the form of self-set goal or default goal, and researchers have found that there are no differences in terms of energy saving between them [49]. Alternatively, the form of goal-setting can be categorized as individual goals and group goals. Group goals with rewards have been found more effective in reducing energy usage [70].

The application of goal-setting intervention is based on goal-setting theory [44], which states that so long as a person is committed to the goal, there is a positive, linear relationship between goal difficulty and outcome. Goal-setting theory has been validated in both laboratory and field settings, using both correlational and experimental designs and numerous dependent variables. Periods have ranged from 1 min to 25 years and positive effects have been obtained at the individual, group, and organizational-unit levels as well [45]. The study from Locke [43] showed that high or hard goals lead to a higher level of task performance because hard goals require people to make more effort in order to be satisfied than low, easy goals. The explanation has been provided that as task performance is a function of both ability and motivation, higher goals may motivate people to further leverage their existing abilities.

3) **Tailored-information Provision**
Tailoring is an approach that makes use of data from a specific individual to provide the most relevant information needed to this individual [36]. In the field of household energy saving, tailored information refers to highly customized and specific information about this household's energy consumption. Studies have shown that tailored information is potentially a more effective way to encourage behavioral changes [3]. Winett, Love, & Kidd [79] supported that households who received an energy audit (providing information on heating and air conditioning) used 21% less electricity, compared to a control group. The results from Gonzales, Aronson, & Costanzo [23] also proved that the experiment group who received tailored information reported a significantly greater likelihood of making the recommended changes than households who did not.

2.2. Consequence interventions

1) **Feedback**
Feedback is a provision of information to households on their energy consumption, which can motivate, or even manipulate, occupants to adopt energy saving behaviors [41]. Feedback can influence household energy saving behaviors because households can associate certain outcomes (e.g. energy savings) with their behaviors [2]. Hayes & Cone [26] examined the effectiveness of providing feedback to the households by dividing the households into the treatment and control group. The treatment group receiving feedback reflected a clear reduction of 4.7% of electricity usage. Grønhøj & Thøgersen [25] conducted an experiment to test for effects of feedback on households' electricity usage through screen display on 20 Danish households for 5 months. Results showed a decrease of 0.8% in comparison with the control group due to more visible electricity consumption for the households to take actions. Generally, the reviews done by Abrahamse et al. [2] on feedback intervention showed that the effectiveness of feedback intervention tends to increase when the feedback is given more frequently. However, exceptions can also be found in the literature that the increase in frequency does not lead to a successful reduction of energy consumption [31].

2) **Rewards**
Monetary rewards, which are often in the form of tax credits, rebates, and subsidies, have been demonstrated that they can lead to a performance increase in many different scenarios [13,21,35;62]. A study conducted by Mizobuchi & Takeuchi [54] managed to correlate the relationship between electricity consumption and conservation incentives by comparing the effectiveness of financial and non-financial factors influencing energy consumption. Results revealed that households responded significantly to the financial incentives provided. In addition, field studies adopted rewards (e.g., money or prizes) to examine household energy saving behaviors indicated that financial rewards have been successful in reducing household energy consumption [78,52,50].

However, two main questions remain in the previous studies. One is the short-lasting problem. Abrahamse et al. [2] evaluated 38 studies about the effectiveness of monetary rewards and concluded that the effectiveness of rewards on energy conservation was short-lived. Another is the validity problem. The effectiveness of monetary reward has been challenged in prior studies. For instance, Mizobuchi [53] studied 53 Japanese households who were offered cash as rewards if they reduced energy consumption for 12 weeks. The results showed that an average reduction rate was negative (−4.8%), which means occupants who exposed to monetary incentives consumed even more electricity.

2.3. Combined interventions

As Osbaldiston & Schott [59] pointed out, one intervention usually combined with other intervention strategies to achieve better performance. Actually, the need for 'multiple approaches' has been supported by many prior research [22,66]. For example, Geller [22] found that providing household energy saving information alone on the pamphlets did not result in a substantial change in energy behaviors; pamphlets must be complemented with other forms of outreach. Also, in Crossley's [14] study, the combination of commitment and stickers, which served as the reminders on energy conservation tips, showed the highest usefulness on home energy conservation.

More recent studies also supported the effectiveness of integrated energy interventions in various forms. For instance, Abrahamse et al. [3] conducted a multidisciplinary study in which the effects of a combination of tailored information, goal setting (5%), and tailored feedback on household direct and indirect energy usage were examined. The results showed that after 5 months' experiment, households exposed to the combined intervention saved 5.1% of direct energy, while households in the control group did not show energy reduction at all. In addition, households exposed to the combined interventions adopted a number of energy saving behaviors and gained more pro-environmental knowledge than the control group. A similar conclusion has been found in the context of dormitories. Bekker et al. [6] investigated the combined use of visual prompts, daily feedback, and rewards to reduce electricity consumption in a university residential hall. The researchers found that after the intervention, energy usage decreased in the experiment hall while no change was found in the control group.

2.4. Market-based interventions

Market-based interventions refer to energy saving strategies that rely on 'market force' or 'invisible hand' producing environmentally friendly outcomes. An example of market-based intervention is peer-to-peer (P2P) energy trading, which refers to the power system operation-based model where people generate their energy from renewable energy such as solar panels, and trade with each other within a local context [60].

The advantage of market-based interventions is that they are self-sufficient. In other words, they do not require external funds from the third party [68]. For instance, the peer-to-peer (P2P) energy trading mechanism allows peers to purchase and sell energy with each other without the involvement of energy suppliers. In addition, market-based interventions are believed to be able to promote active citizenship and the 'common purpose', which has great potential to bring economic and technical benefits in energy efficiency [80]. Yet, questions about peer-to-peer energy trading remain here. For instance, the framework of community energy market proposed by Shamsi, Xie, Longe, & Joo [69] did not consider flexible demand. Flocchini, Nayak, & Xie [19] provided a price-based scheme for flexible demand but this model was challenged by the energy storage problem.

2.5. Gamified interventions

Gamified intervention, also known as gamification, is a form of intervention defined as 'the use of game elements in household energy contexts to improve user experience and engagement' [61]. As distinguished by Nicholson [56], gamification includes reward-based gamification (e.g. points, levels, badges, and leaderships, etc.) and meaningful gamification, which employs game design elements such as reflection, information, and choice, etc. Reward-based gamification may lead to immediate and short-term behavioral changes, while meaningful gamification aims for long-term habitual changes. Meaningful gamification involves interaction, through which, participants can observe and learn [28,65]. In addition, meaningful gamification is more emotionally entertaining, thus, participants are likely to stick on the involvement for a long time.

Gamified energy interventions offer a potentially productive area for exploration in energy behavioral change and energy demand reduction [11]. Results from Reeves, Cummings, Scarborough, & Yeykelis [63] demonstrated a significant increase in energy-efficient behaviors (e.g., turning off room lights) after participants playing the game for 30 min in a lab experiment. In the field test of the same game, smart meter data showed a significant reduction in electricity usage after households playing the game.

In summarizing the literature, these results highlighted how different household energy saving interventions improved residential energy conservation. However, conventional energy saving interventions, such as tailored informational feedback provision and monetary rewards, usually require external funds to support the sustainability of these interventions, which imposes a fiscal burden to energy policy agencies. Thus, based on previous research, the development and examination of a holistic cost-efficient household energy saving strategy – HESO are proposed.

3. Conceptual framework of HESO

Household Energy Saving Option (HESO) is an option-based self-sufficient energy saving intervention, aiming to encourage energy conservation in residential buildings. The framework of HESO consists of five factors, which can be abbreviated as 'TIMES': 1) theoretical foundation (T); 2) integrated interventions (I); 3) Market Premises (M); 4) Energy sustainability (E); and (5) Stakeholders (i.e. households, issuers and market regulators) (S). The overview of HESO conceptual framework shows different layers of HESO (Fig. 1). Theoretical foundation is the first layer, based on which the gamified integrated interventions can build up. With the market premises guaranteed by regulators (i.e. energy market authorities), HESO is able to be traded between buyers (i.e. households) and issuers successfully and eventually, to achieve energy saving and energy behavior changing goals.

3.1. Theoretical foundation (T)

Derived from binary option, HESO can be viewed as a special binary option with the underlying asset as energy reduction amount. Thus, the payoff and pricing mechanism of HESO are based on option theory. As we can see the payoff of HESO from Fig. 2, households may either receive rewards when the condition is met, or lose their initial payment. It is worth noting that the potential losses and gains are both capped. Limited losses make HESO easier to be accepted by households, as most people are risk-averse and do not prefer products with unlimited risks [67]. Also, limited gains avoid HESO being misused for a product pursuing profits rather than an intervention to encourage energy saving. HESO intervention differs from financial options trading in such a way that participants have in control of their energy-related behaviors to gain incentives as opposed to the financial options, which rely on the performance of the external underlying assets.

The pricing of HESO is based on Binomial pricing model in option valuation [51]. Consider HESO pays S$1($S1 = USD$0.71) at date T if users meet the energy saving goal; else, users will get nothing. Therefore, the payoff of HESO (x) is:

$$\mathrm{x} = \begin{cases} 1, & S(T) > K \\ 0, & otherwise. \end{cases} \tag{1}$$

where S(T) is the actual energy reduction;

K represents the pre-set energy saving goal.

The expected value of HESO is:

$$E(x) = 1 * Prob(x = 1) + 0 * Prob(x = 0) = Prob(\mathrm{S(T)} > \mathrm{K}) \tag{2}$$

Using the calculation of present value for real option, the present value HESO at time t is:

$$\mathrm{e}^{-\mathrm{r(T-t)}} * E(x) = \mathrm{e}^{-\mathrm{r(T-t)}} * Prob(\mathrm{S(T)} > \mathrm{K}) \tag{3}$$

where r is the discounted rate;
T is the expiry date.

3.2. Integrated interventions (I)

HESO is a hybrid intervention combined with tailored informational feedback, goal-setting, and monetary rewards to encourage household energy saving. Specifically, informational feedback refers to processed energy consumption data and personalized information presented to households on a weekly basis. Household energy consumption data is visualized in the form of a digital report with a bar chart via cell phones. There are two main reasons that visualized information feedback is adopted. One is because energy consumption is quite abstract. Households may not have a concrete idea of how much effort they need to make in order to reduce 1 kWh electricity. Another is that energy consumption does not have strong personal relevance to households. Therefore, when energy consumption is abstract, people may not have initiatives to spend extra effort to understand the concept. In this case, it is important to visualize the informational feedback so as HESO users are able to interpret energy consumption data at first glance and have a clear understanding of how far they still need to go in order to achieve their pre-determined goals.

The design of HESO also includes the intervention of multiple goal-setting, that is to say, HESO allows households to have various energy saving goals in multi-stages. For example, households can

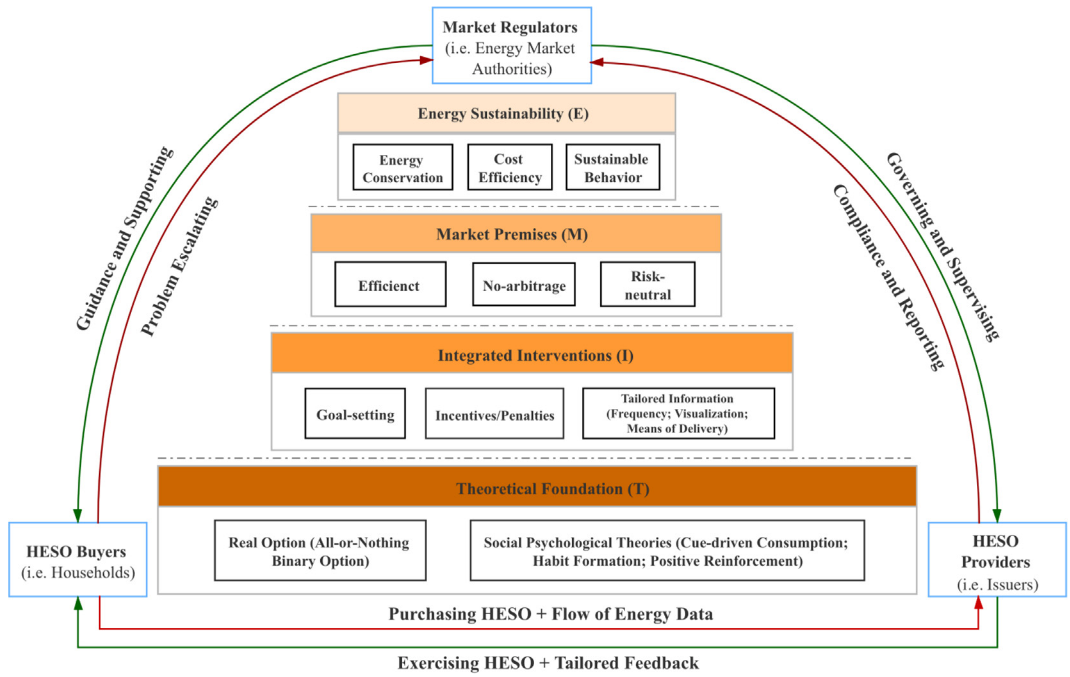


Fig. 1. Conceptual Framework of HESO (The framework is presented as "TIMES", including five elements constructing HESO, which are Theoretical Framework (T), Integrated Intervention (I), Market Premises (M), and Energy Sustainability (E).)

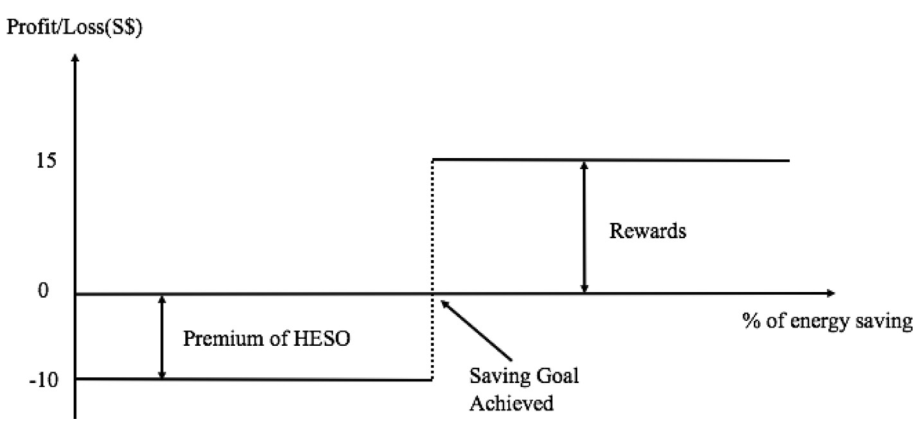


Fig. 2. Payoff of HESO.

choose the energy saving goals embedded in HESO ranging from 5% to 20% based on their baseline consumption or their personal preference. In compliance with goal-setting theory [44], the more difficult the goal is, the better energy saving performance is expected and the higher monetary reward is attached.

Monetary reward is attached to goal achievement in the design of HESO intervention as mentioned. The combination provides extra motivation beyond conventional monetary subsidies. In our design of HESO, users are motivated by the probability to receive reward if they will achieve their energy saving goals at the expiry date. This feature is intended to keep the high engagement and participation.

3.3. Market premises (M)

The premises of efficient HESO market guarantee that the prices of HESO reflect all information in the trading market, making it impossible for the issue of 'free-riders' (i.e. buyers to gain rewards without saving sufficient energy). The market premises behind HESO trading include no-arbitrage equilibrium assumption, risk-neutral assumption, and efficient market hypothesis.

- No-arbitrage Equilibrium Assumption
  The notion of absence of arbitrage is a central concept in HESO trading. Ross [64] defined the concept of arbitrage as 'the state where there is an opportunity to instantaneously buy something for a low price and sell it for a higher price'. The no-arbitrage equilibrium was derived from the assumption that each individual pursues his or her own profit maximization. In no-arbitrage equilibrium, asset price equals its value and there is no risk-free arbitrage opportunity in market equilibrium. In the electricity market, electricity is the traded commodity. That is to say, under the no-arbitrage equilibrium assumption, there is no chance of households receiving rewards while they do not perform energy saving actions in HESO trading.
- Risk-neutral Assumption
  The core of risk-neutral assumption states that the market equilibrium price of HESO is not related to households' risk atti-

tudes. Ross [64] has proved that asset valuation under the risk-neutral world can also be applied to a non-risk-neutral world, i.e. real world. Therefore, despite households have different risk attitudes, the market equilibrium price of HESO is the same regardless of their risk attitudes.

- Efficient Market Hypothesis
  The primary assumption of the efficient market hypothesis is that information is universally shared and asset prices fully reflect all available information [47]. In other words, if HESO trading market is efficient and complete, the value of HESO is unique. However, if the price of HESO cannot reflect all the information in the market, there will be gaps between the value of HESO and its market price. In this situation, there will be arbitrage opportunities, where households may receive rewards for free. Therefore, the efficient market and no-arbitrage equilibrium assumptions are sufficient and necessary conditions for each other.

3.4. Energy saving sustainability (E)

Energy saving sustainability refers to HESO's design and operation objectives of achieving sustainable energy saving in the long term. Three components of energy saving sustainability are 1) sustainable household energy reduction; 2) cost-efficiency of HESO, and 3) habituation of energy saving behaviors for households. Specifically, sustainable energy reduction pursues a consistent reduction of energy usage after the intervention. Cost-efficiency is used to measure the 'cost' taken by HESO providers over 'benefits' for all stakeholders from the economic aspect. Habituation of energy saving behaviors refers to occupants' energy behavior change after the intervention.

3.5. Stakeholders (S)

Successful implementation of HESO encourages participation and interaction of all stakeholders, which include households (buyers), issuers (sellers) and regulators. Households are the buyers of HESO, who can be divided into three sub-groups, according to their energy saving performance. Specifically, households (SwoG) are those who save energy but fail to hit their energy saving goals. Households (woS) are those who do not save energy at all and households (SwG) are those who successfully achieve their energy saving goal. Only households (SwG) are able to receive rewards at the expiry date. It is worth noting that when households make an effort to reduce energy usage and hit the goals with HESO, they not only maximize their own utilities from implementing energy saving measures, but also contribute to society and the environment by lowering greenhouse gas emissions.

Issuers are corporations, governments, or agencies that sell HESO to households. As non-profit organizations, the aim of the issuers is to promote energy saving in residential buildings and provide a platform for households to participate in HESO intervention. In addition, issuers in HESO market also need to gather energy usage data of their customers and provide informational feedback to help residents reduce energy consumption more effectively. The issuers add value to the whole society by investing their time and knowledge to the probability of successful trading of HESO among people.

Regulators are another important role in HESO market. Regulators are agencies having a specific range of duties and responsibilities that enable them to act independently from any other market stakeholders. Their duties include guarantee the efficiency of HESO market and providing sufficient cash-flow liquidity into the market, etc. The role of stakeholders in HESO market is presented in Table 1 below.

3.6. Systematic equilibrium

From a systematic point of view, HESO can achieve systematic dynamic equilibrium where the gains from households who achieved their energy saving goals are compensated by the premiums paid by those who failed to achieve their goals. In other words, issuers' pay-out equals the cash flow incoming from households to issuers. Therefore, the net balance of issuers is expected to be zero. The cash and energy flows of HESO system are presented in Fig. 3.

The sum of net profit and loss (i.e. net balance) of the system follows:

$$P = \left(\sum_{i=1}^{n} S_i\right) + G - \left(\sum_{i=1}^{n} K_i\right) - T \tag{4}$$

where S_i is the premium collected from household i;

G is the subsidy provided by regulators;
K_i is the rewards paid by issuers to household i who succeeded in achieving energy saving goal;
T is the transaction cost.

Letting P = 0, then:

$$\sum_{i=1}^{n} K_i = \left(\sum_{i=1}^{n} S_i\right) + G - T \tag{5}$$

However, in practice, the net balance may fluctuate around zero. In this situation, the positive balance will be stored in a reserve fund for further usage when issuers do not have sufficient cash-flow liquidity to meet their obligations.

4. Field experiment

This research concentrates on assessing the effectiveness of HESO on household electricity saving in public residential buildings of Singapore because energy consumption in residential sectors in Singapore is increasing over the past decades, especially in the public housing sector. In Singapore, 80% of public housing occupied 60% of overall household energy consumptions and among all energy resources consumed by households, electricity constituted 88.28% [16], therefore, this study specifically focused on household electricity consumption. In the following paragraphs, 'electricity consumption' and 'energy consumption' may be used interchangeably.

4.1. Research design

A field experiment is carried out to test the effectiveness of the innovative household energy saving strategy – HESO on household energy conservation. The experiment includes two rounds (each round lasts for two weeks), followed by a post-observation period that lasts for another two weeks. The first round of HESO intervention starts from week 1 to week 2, with 5% of electricity saving as a goal, and the reward for the households who achieve the goal is S $15 (USD$10.65). Those who succeed in achieving energy saving 5% goal in the first round are eligible to join the second round of HESO intervention. The second round of HESO intervention starts from week 3 to week 4, with 10% of electricity saving as a goal and the reward is S$20 (USD$14.2) instead. During the experiment period, tailored weekly electricity consumption reports are provided to participants via WhatsApp (a popular social network app). The intervention will be suspended at the end of round two, but meter reading will be recorded for households' electricity consumption during the post-experiment period for another two weeks. The experiment procedure for HESO intervention is illustrated in Fig. 4.

Table 1
Roles and Responsibility of Stakeholders in HESO Trading.

Households			Issuers	Regulators
SwoG: Save energy but not hit the goal	woS: Not save energy and not hit the goal	SwG: Save energy and hit the goal		
• Pay premium to issuers • Receive energy feedback	• Pay premium to issuers • Receive energy feedback	• Pay premium to issuers • Receive energy feedback • Receive reward	• Collect premium from households • Audit energy consumption • Provide energy consumption feedback to households • Pay reward to Households (SwG)	• Disclose and monitor HESO trading information • Mitigate transaction cost and liquidity risk

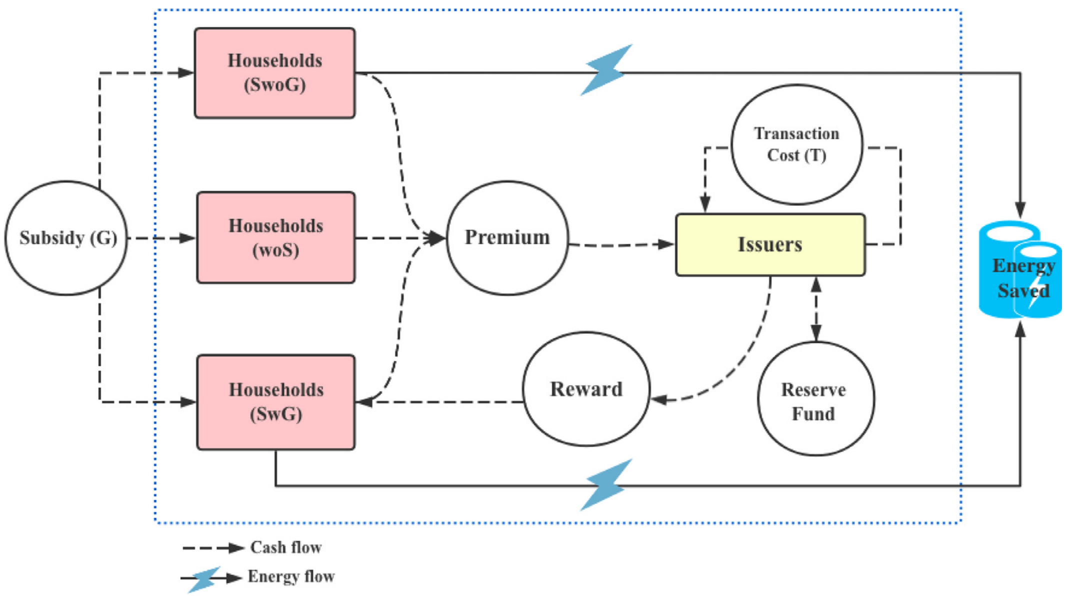


Fig. 3. Cash and Energy Flow in the System of HESO.

The feedback provided to households consists of a bar chart and customized comments. In contrast to other types of consumption, energy consumption is 'invisible' and 'untouchable' [57]. Thus, a bar chart is used for the visualization of household energy consumption data, which may help residents understand their energy reduction level with regards to the baseline of their energy consumption and the pre-determined energy saving goal. Customized comments on the household's energy performance aim to provide encouragement or pressure on households based on their energy saving performance. The research from Thondhlana & Kua [75] supported that energy consumption feedback with words of encouragement makes households more willing to save energy. Here is an example of the encouraging message sent to the households in this study: *'Congratulations! You have saved 17.1% in com-*

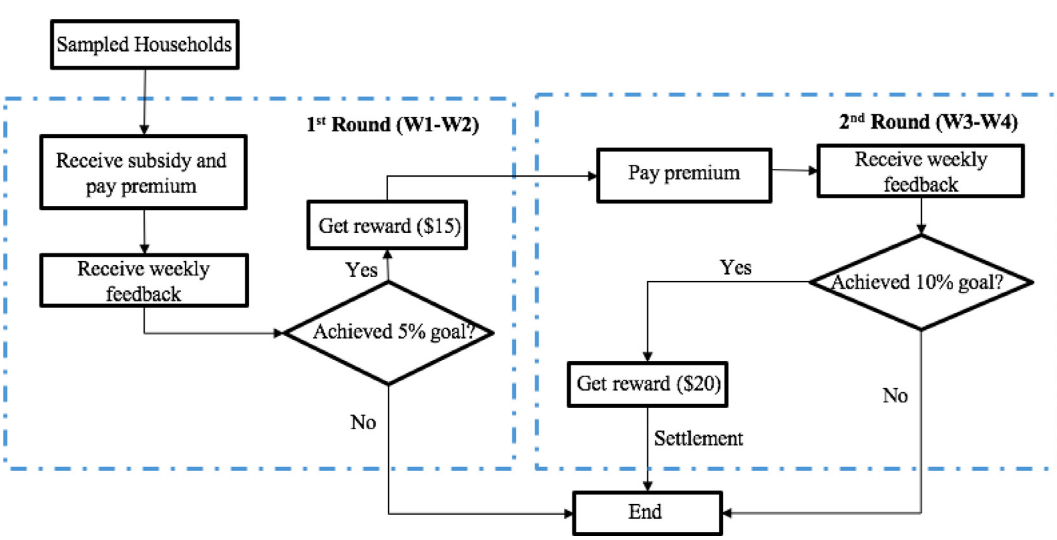


Fig. 4. Procedure of HESO trading.

parison with your baseline consumption. Well done! Remember the key to success is consistency'. Besides, participants are also encouraged to send back their feedback, comments, or questions via WhatsApp, which increases the interaction of households and HESO providers during the experiment. An example of the home energy report is framed as below (see Fig. 5).

The changes in household energy consumption are calculated by Percentage in Change (PiC), which is as follows:

$$PiC = \frac{U_r - U_o}{U_o} \times 100\% = \frac{\Delta U}{U_o} \times 100\% \tag{6}$$

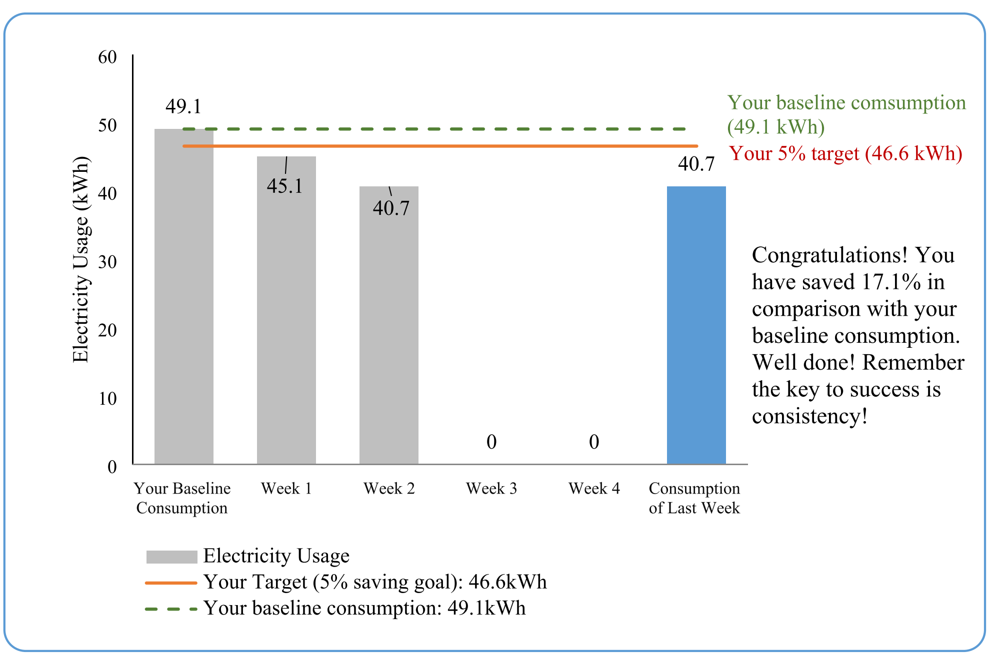
Specifically, the baseline electricity consumption was calculated by the average of households' historical electricity consumption for the past three months. It is because that the average historical daily temperature from August to December 2018 in Singapore varied very slightly, ranging from 27.3 °C to 28.5 °C (see Appendix). Therefore, the daily air temperature during baseline setting period and experimental period was quite similar. Moreover, prior studies have proved that households' electricity consumption in Singapore was mainly affected by various energy conserving measures promoted by the government, rather than temperature. For instance, the electricity consumption per-capita in Singapore during 2008 to 2016 was much lower than that during 2005 to 2007, but the temperature in Singapore was almost same during these two periods. The sudden reduction of the energy usage was because of the energy saving policy taken by Singapore government since 2008 [42]. The reason that PiC, rather than the absolute value, is employed is because that percentage value allows households to compare their current energy consumption with their own baseline, which guarantees the fairness of HESO for households with different historical electricity consumption.

This research adopts a field experiment with two treatment groups of different energy saving goals (energy saving goals for treatment group A and B are 5% and 10%, respectively) and a control group. Households in treatment groups participate in HESO trading and receive tailored feedback about their weekly energy saving performance, while households in the control group are not expected to receive any intervention but their electricity consumption will be recorded (refers to Table 2).

4.2. Data collection

189 participants were recruited from HDB communities through the door-to-door visit, phone call, and online recruitment after the approval from HDB during Nov. to Dec. of 2018. The selected communities (refer to red dots in Fig. 6) were located in North, East, North-East and West of Singapore, as the central district of Singapore is mainly for business use. Specifically, 53 households (28.04%) were in the North, 45 households (23.81%) were in the East, 37 households (19.58%) were in the North-east, and 54 households (28.57%) were in the West. The samples in each zone well represented the distribution of public residential buildings in Singapore. Households recruited were restricted to those living in the public housing sector (i.e. HDB) with 4 or 5 rooms, since the fluctuation of energy consumption is more significant in larger flats. It is worth noting that as HESO is a new intervention to most households, in order to increase their interest to participate, households were provided with a one-time subsidy for purchasing HESO (worth S$10 = USD$7.1). The sampling rule used in this study is non-probability sampling, which is a commonly used sampling method and the results were acceptable. No significant deviation was found between the sampled and national average electricity consumption patterns [16]. The electricity consumption data were manually recorded by our research team from households' electricity meters on a weekly basis. After the experiment, a short interview was conducted with several households to collect information about their energy behaviors and attitudes towards HESO intervention.

The process of data collection included three stages, which has been illustrated in Fig. 7.



(**Disclaimer:** All information and data contained in this report are based on individual household energy consumption, personal preferences, research articles, and market conditions, individual experience and research literature and it is subject to change. It is for the reference only.)

Fig. 5. Weekly Informational Feedback (Disclaimer: All information and data contained in this report are based on individual household energy consumption, personal preferences, research articles, and market conditions, individual experience and research literature and it is subject to change. It is for the reference only.)

Table 2
Experimental treatment on different groups.

Experiment Groups	Interventions			
	Goals setting	Weekly feedback	HESO trading	Meter reading
Treatment Groups	√*	√	√	√
Control Group	×	×	×	√

*Treatment group A (TG A): Goal = 5%; Treatment group B (TG B): Goal = 10%

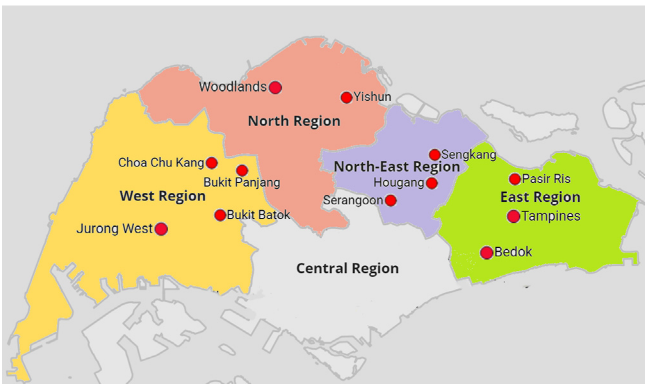


Fig. 6. Location of Selected Households in Singapore.

4.3. Data analysis

Data coding and clearance were performed before analyzing households' electricity consumption data by Difference-in-Difference (DID). First of all, each household was assigned to a unique participant ID for confidentiality purposes. Demographic variables such as education and income level were coded numerically. Secondly, for families who were absent for over 2 weeks or their residential structure altered (e.g., relatives come for homestay) during the experiment period, their electricity data were view as invalid. In addition, households that decided to withdraw from the experiment will be filtered out from data analysis as well. Outlier detection was carried out using Boxplot in R. The electricity consumption data, which were larger than Q3 (the median of the upper half of the data set) at least 1.5 times the interquartile range or smaller than Q1 (the median of the lower half of the data set) at least 1.5 times the interquartile range, were considered invalid. Extreme value was re-examined against the number of members in the household. 101 out of 189 samples were considered valid after data clearance. Among them, 36 households were in HESO treatment group and 65 households were in control group.

The changes in home energy consumption caused by HESO intervention were estimated by Difference-in-Difference (DID) analysis. DID has been widely used to estimate the intervention effect by comparing the changes of outcomes over the intervention period between the intervention group and the control group [7]. DID is the preferred method, as it not only can remove biases from the constant difference between control group and treatment group, but also eliminate biases from comparisons over time in the treatment group that could be the result of trends due to other causes of the outcome. Moreover, DID has more freedom on the requirement of data randomness. Therefore, DID has been chosen in this study. To be specific, the effectiveness of HESO on home energy saving is estimated by DID model as follows:

$$Y_{i,g,t} = \gamma_g + \lambda_t + \beta * D_{g,t} + \varepsilon_{i,g,t} \tag{7}$$

where independent variable Y is Percentage in Change (PIC);

iRefers to unit of households;
g represents experimental groups (1 = treatment group, 0 = control group);
t represents experimental stages (1 = post-treatment period, 0 = pre-treatment period);
γ, λ are group and fixed time effects, respectively;
D is a dummy variable which equals to 1 for treated group in treatment period, and equals to 0 otherwise;
β represents the treatment effects in DID model;
ε is a stochastic error term.

To evaluate the economic efficiency of HESO, cost-effectiveness analysis is employed. Cost-effectiveness analysis is a form of analysis that compares the relative cost and outcomes of an action, which has been applied in the planning and management of many types of treatment [39]. The cost-effectiveness (ℂE) of HESO is defined as the direct cost (φ) of HESO divided by the market value of total energy saved by households (amount of electricity saved (ω) × electricity tariff (θ). In general, the cost-effectiveness (ℂE) is defined as:

$$\mathbb{C}E = \frac{\varphi}{\omega} x \frac{1}{\theta} \tag{8}$$

where φ is the direct cost of HESO taken by the providers of HESO (i.e. energy policy agencies);

ω represents the amount of electricity saved by households;
θ is the electricity tariff, which is adjusted quarterly in Singapore.

Cost efficiency (ℂE) of HESO is calculated under two different scenarios –with subsidy, which is the scenario of current experiment, and without subsidy, which offers an alternative consideration for energy policy agencies. The benchmark for the cost-

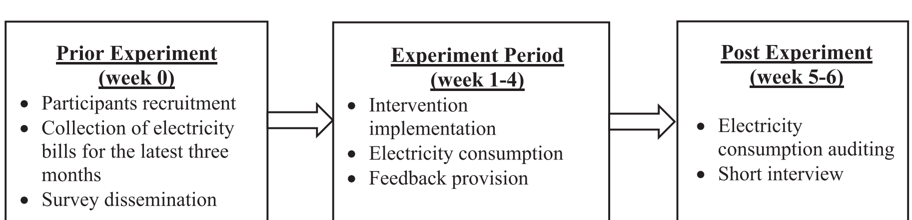


Fig. 7. Process of data collection.

effectiveness is ℂE equal to 1, since the direct cost of HESO equals the market value saved by the households when ℂE is 1. If ℂE is less than 1, HESO is considered cost-effective and vice versa.

5. Results

The descriptive statistics of households in full sample, HESO treatment group A (TG A: goal 5%), HESO treatment group B (TG B: goal 10%) and control group are presented in Table 3. The gender and age refer to family representative's gender and age. More than 50% of the participants in the experiment are younger generation (age below 35 years old) and the majority of households have 3 to 5 family members. Above half of the households have an education level of university degree and the majority of them indicated that their monthly total income was between S$4000 to S$5999 (USD 2825 to USD 4237).

The trend of electricity consumption with error bars for both experimental group and control group was presented in Fig. 8, which revealed the fluctuation of household energy consumption in TG A, TG B and control groups. The decreases of home energy consumption were found in the experimental groups (TG A and TG B) as well as control group. Specifically, on average, the electricity consumption of experimental group and control group was 13.64% and 6.15% less than the baseline consumption, respectively. T-test has conducted to examine the difference of energy reduction in the two groups. Significant difference was found between the household energy conservation of experimental group and control group (p-value = 0.008), which proved that HESO significantly encouraged households to reduce electricity usage. The slight decrease of electricity consumption in control group indicated that Hawthorne effect might exist, which means that households changed their energy behaviours due to their awareness of being observed.

The overall energy saving trend of HESO treatment group showed that energy consumption reduced at the end of week 1 and then it slightly rebounded in week 2 and reached the highest point at the end of week 3, followed by a sharp reduction at the end of week 4. After the experiment, household energy consumption gradually increased in week 5 and week 6.

The results of the quantitative analysis of the comparison of household energy reduction between experimental group and control group was presented in Table 4 through Difference-in-Difference (DID) analysis. The effect of HESO on home energy reduction was 8.18%, with energy saving goal of 5%, while it increased to 12.56% with the energy saving goal of 10%. It seemed that with the increase of energy saving goal, the stimulus of household energy saving was reinforced. However, the results of the post-intervention observation indicated that two weeks after the intervention, HESO group's energy consumption rebounded to the level that was not significantly different than their baselines.

In the current experiment scenario, cost efficiency of HESO equalled 0.72, which was less than 1. The results implied that the market value of total energy saved by households was greater than the cost of HESO's implementation taken by energy policy agencies. To be specific, Table 5 showed that the amount of electricity (kWh) saved by adopting HESO was 1097.3 kWh and 747.4 kWh with the energy saving goal of 5% and 10%, respectively. Given the electricity tariff in the open market was S$0.26 per kWh in Singapore during the experiment period, the total saving was S $479.62 (USD$340.53). The total cost for the experiment was S $345 (USD$244.95), which is less than the amount of total saving values. From the systematic perspective, the net gain for the issuers of HESO is S$15 (USD$10.65), which will be saved in the special account and rolled into the following round of trading.

It is worth noting that subsidies of S$10 (USD$7.1) per household were provided to increase participation in the scenario of current experiment, which equalled S$360 (USD$255.60) in total. While in the alternative scenario that no subsidies would be

Table 3
Demographic profile of respondents in experimental group.

	Full Sample		HESO				Control	
			TG A (goal: 5%)		TG B (goal: 10%)			
Demographic attribute variables	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Gender								
Male	46	45.54	15	41.67	9	42.86	31	47.69
Female	55	54.46	21	58.33	12	57.14	34	52.31
Age								
18–35	56	55.45	25	69.44	14	66.67	31	47.69
36–55	39	38.61	7	19.44	4	19.05	32	49.23
>56	6	5.94	4	11.11	3	14.29	2	3.08
Number of family members								
2	4	3.96	2	5.56	2	9.52	2	3.08
3	21	20.79	6	16.67	4	19.05	15	23.08
4	37	36.63	10	27.78	6	28.57	27	41.54
5	24	23.76	12	33.33	6	28.57	12	18.46
6	11	10.89	6	16.67	3	14.29	5	7.69
7	4	3.96	0	0.00	0	0.00	4	6.15
Educational Level								
Primary school and below	1	0.99	0	0.00	0	0.00	1	1.54
Junior high school	4	3.96	2	5.56	2	9.52	2	3.08
High School	25	24.75	4	11.11	3	14.29	21	32.31
Undergraduate	59	58.42	28	77.78	14	66.67	31	47.69
Graduate and above	12	11.88	2	5.56	2	9.52	10	15.38
Monthly household income (S$)								
<1999	4	3.96	1	2.78	1	4.76	3	4.62
2000–3999	16	16.16	5	13.89	3	14.29	11	16.92
4000–5999	28	27.72	11	30.56	6	28.57	17	26.15
6000–7999	14	13.86	6	16.67	3	14.29	8	12.31
8000–9999	12	11.88	6	16.67	3	14.29	6	9.23
>10,000	15	14.85	3	8.33	3	14.29	12	18.46
Not available	12	11.88	4	11.11	2	9.52	8	12.31

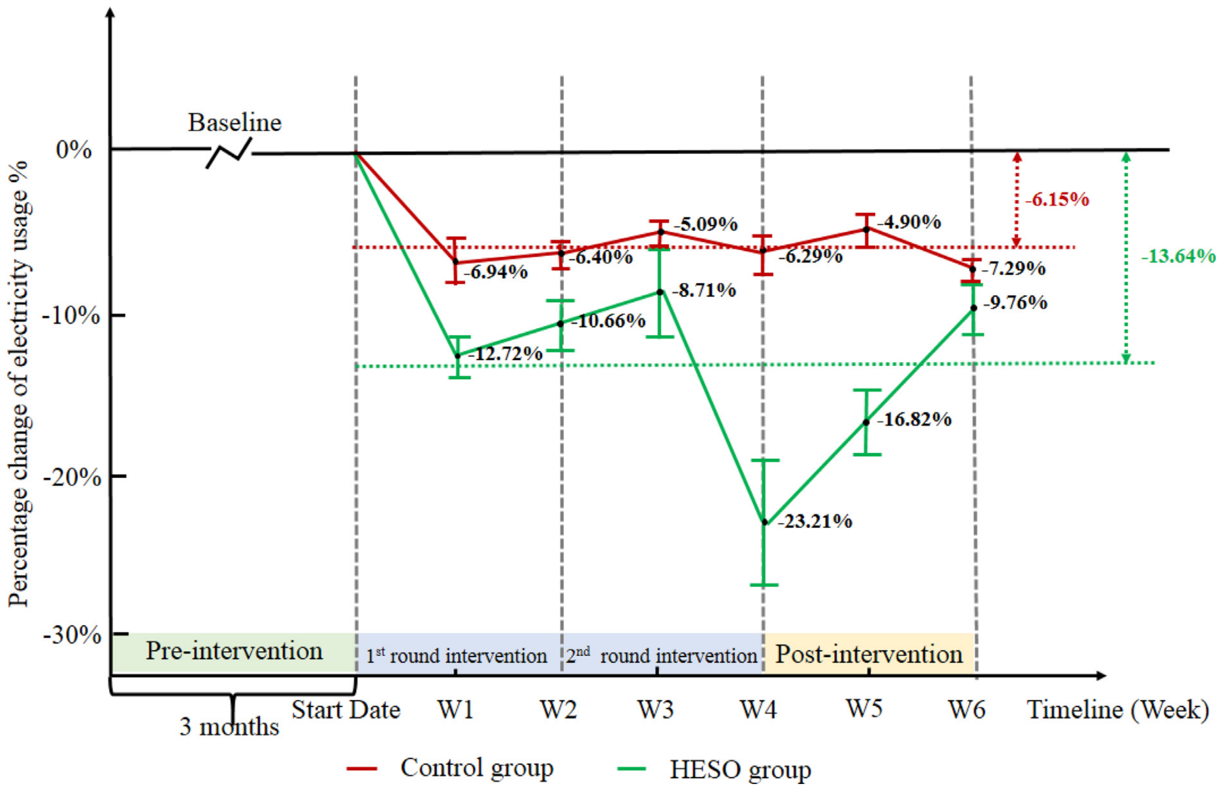


Fig. 8. Households' Energy Consumption Changes (relative to household baseline).

Table 4
Changes of Home Energy Consumption in Experimental Group through DID analysis.

	Intervention		Post intervention
	TG A (goal: 5%)	TG B (goal: 10%)	
Intercept	0.00	0.00	0.00
	(1.45)	(1.67)	(1.50)
Treatment	0.00	0.00	0.00
	(2.03)	(2.34)	(2.11)
Time	−8.14%***	−5.44%*	−9.30%***
	(2.03)	(2.34)	(2.11)
Treatment*Time	−8.18%**	−12.56%***	−3.34%
	(2.78)	(3.30)	(2.92)
AdjustedR^2	0.46	0.41	0.33
No. of Observations (1)	36	21	32

(1) Sig. codes: *** p < 0.001, ** p < 0.01, * p < 0.05
(2) Standard deviation are presented in brackets.

provided, this amount of money would be collected from households for the purchase of HESO. The result of the two scenarios discussed above is summarized in Table 5.

6. Discussions

6.1. Underlying theories explaining energy saving changes

Changes in household energy saving were observed during different stages, which can be explained by the theories as follows.

- *Positive self-reinforcement to enhance saving behaviors*
After participating in HESO intervention in the earlier stage, households involving in the second round accumulated more knowledge and positive experience of saving energy, which allowed them to escalate the saving amount more than twice. Positive reinforcement theory in psychology indicated that the

Table 5
Results of Cost-efficiency Analysis of HESO.

Scenarios	Parameters	TG A (goal: 5%)	TG B (goal: 10%)	Total
With subsidy (Current experiment)	Amount of electricity saved (Kwh)	1097.31	747.40	1844.71
	Energy saving in dollar (S$)*	285.30	194.32	479.62
	Reward paid to households (S$) **	315.00	240.00	555.00
	Premium collected from households (S$)**	0.00	210.00	210.00
	Cost borne by issuers(S$) **	315.00	30.00	345.00
	Cost efficiency ratio	1.10	0.15	0.72
Without subsidy	Amount of electricity saved (Kwh)	1097.31	747.40	1844.71
	Energy saving in dollar (S$)*	285.30	194.32	479.62
	Reward paid to households (S$) **	315.00	240.00	555.00
	Premium collected from households (S$) **	360.00	210.00	570.00
	Cost borne by issuers(S$) **	−45.00	30.00	−15.00
	Cost efficiency ratio	−0.16	0.15	−0.03

(1) * Electricity tariff = S$0.26 (USD$0.18)
(2) ** The relationship among individual parameters is as follows: 'Cost borne by issuers' = 'Reward paid to households' – 'Premium collected from households'

sense of satisfaction motivates people to pursue higher achievement [74]. Participants were provided with tailored feedback and monetary stimulus, which gave them a sense of satisfaction and further reinforced their energy saving behaviors in long term [2,52]. The above theory was supported by the results of the short interview after the experiment. One of the households said that the frequency of performing electricity conservation actions, such as "turning lights off when nobody is in the room", actually increased after receiving the positive feedback from our research team.

- *Motivation re-adjustment in the goal transition period*
It is worth noting that household energy saving changed from 10.66% to 8.71% when electricity saving goal increased from 5% to 10%. Although individuals provided with the higher goal are expected to have a higher intention, they may not translate their intention into actual energy saving behaviors [40]; [84]. The results of the post-experiment interview indicated that households' energy saving intention was influenced by households' energy behaviors include households' attitudes towards environmental protection, their ability to control energy behaviors at home, and the intention to save energy. Therefore, participants may need a period to adjust their energy behavioral variables in order to bridge the 'intention-behavior gap' when there is a new energy saving goal. Such re-alignment may cause fluctuation of household energy conservation. Social support and positive feedback provision can accelerate the re-adjustment period, as the perceived difficulty of goal setting can be changed with more positive information [81].
- *Deadline-approaching effect to nudge behaviors*
Household energy saving was observed to increase by almost three times within one week when the deadline approached. This may be due to time pressure generated by the settlement of the experiment, which was scheduled at the end of week 4. Time pressure refers to the imposition of a deadline and the subjective perception of time pressure. When households perceived time pressure, they may choose filtration or acceleration to adapt to the imposition of the deadline [48]. If acceleration mode is chosen, time-pressured people may work faster, get more tasks done, and have better performance. The findings extend the understanding of the theory of time pressure and its influencing factors on household energy saving decision-making process.
- *Repeated stimulus and cue-driven consumption*
With the removal of HESO intervention, household energy saving decayed about 7% one week after the experiment. The framework that is particularly useful to explain the decay effect is the cue-driven consumption model [38]. Based on the cue-driven consumption model, the intervention is a repeated 'cue' that can temporarily lower the utility of energy consumption. When the 'cue' is removed, consumers' energy usage would return to its 'un-cued' level and people may lose the motivation to save energy after a week or two. When the 'cue' keeps active, households rehearse the habit of saving energy over and over again, which may potentially cause the persistent effect. Therefore, repeated stimulus plays an important role in forming a habit over a sustained period of time [17]. In the post-experiment interview, one of the households who succeeded in both rounds of HESO trading also proved the effectiveness of repeated cue by saying "*After receiving the feedback and reward over and over again, I have developed a habit of reducing electricity consumption at home*". Based on cue-driven consumption theory and the feedback from participated households, repeating the intervention until participants develop a new habit is highly suggested.

6.2. Key determinants of HESO's success

The successful implementation of HESO can be influenced by components from the aspect of regulators, issuers (i.e. HESO providers), and participants. Since the influencing factor from the aspect of participants is straight-forward – reducing energy usage to hit the goal, the following paragraphs mainly focus on the determinants of HESO's successful implementation from the aspects of regulators and issuers.

1) **Perspective of Regulators**

- *Regulating information flows and enacting mandatory-disclosure rules*
Asymmetric information is traditionally regarded as a major source of market inefficiency, which also applies to HESO trading market, where issuers have all kinds of trading information and personal private data. For the sake of public information security, as well as improving market efficiency, justice and fairness, trading information need to be regulated by the city government. To align with Personal Data Protection Act (PDPA) in Singapore, households' personal data such as telephone number, home address, and identification number must be protected by regulators to avoid misuse from any other third parties. Issuers may collect the information under the consent of participants, but they are not allowed to disclose or trade these data. In addition, enacting mandatory-disclosure rules regarding reporting and publishing HESO trading information, such as daily trading volume, households' goal achieving rate, and energy saving amount, is essential. On the one hand, the disclosure of market trading information ensures issuers and buyers are equally knowledgeable. The symmetric information creates an opportunity for households to make a more rational decision when they participate in HESO trading. On the other hand, reporting market trading information is mandatory in terms of market risk governance. Once an abnormal value is reported, necessary actions such as activating a circuit breaker mechanism can be taken place immediately.
- *Enhancing credibility of HESO through third-party endorsement*
Since households are not familiar with HESO, they may not trust this intervention very much, so their willingness to accept HESO may relatively be low at the beginning of HESO's implementation. With the aim to gain the trust of HESO among households, the administrative entities (i.e. regulators) may consider employing the third-party endorsement, which can alleviate the information gap between HESO providers (i.e. issuers) and potential buyers (i.e. households) and act as an informational intermediary to convey useful information about HESO to households [84,85]. Most importantly, the third-party endorsement can serve as a signal of trustiness, which may largely improve the credibility of HESO and attract more potential participants to save energy [86]. Additionally, third parties such as expert reviews and consumers' reports can provide an assessment of the intervention and its utility before potential buyers making purchasing decisions.
- *Providing cash-flow liquidity to mitigate issuers' credit risk*
The results indicated that HESO is able to keep systematic financially balanced when it functions well. The functioning of HESO requires sufficient cash-flow liquidity, so that issuers are always able to provide monetary rewards to households (SwG). In the case of no regulators' interference, the cost borne by issuers will be high at settlement points, therefore, issuers may face huge liquidity risk. To mitigate liquidity and credit risk of HESO's trading, regulators may consider to set up a credit granting system, in which, regulators determine a maximum amount of credit limit for issuers. When issuers' cash-flow liquidity is

low, they have the right to apply for the loans under their credit limit from regulators and pay off the unexpected financial obligations. With the credit granting system, issuers have stronger credit risk resistance ability.

Ideally, the credit limit should reflect the future earning potential of issuers [71], and therefore, should be calculated based on the estimated number of participants and the amount of premium of HESO in the future. Developing a set of appropriate indices that allow regulators to calculate issuers' future earning ability may be a promising area for future research to explore.

2) **Perspective of Issuers**

- *Maintaining systematic financial balance through adjusting the ratio of premium to reward*
  As for issuers, it is critical to keep the incoming cash flow greater than the payoffs, otherwise the systematic financial balance would be broken. To maintain the balance in the long run, finding the rational ratio of HESO's premium to reward is the priority. Reward, on the one hand, is able to boost participants' motivation to reduce energy usage. The higher reward is expected to stimulate higher household energy reduction. On the other hand, higher reward means the higher premium, which will discourage households' willingness to participate. Therefore, the rational ratio of HESO's premium and reward guarantees that the sum of premium collected from households is able to cover the cost of issuers while the premium is still attractive to households. From the results of the two-round experiment, it is suggested that the rational ratio of premium to reward is from 1:2 to 1:1.5. The ratio seems much smaller than the number in the betting industry, which was reported as 1: 0.068 on average in the U.S [73]. The difference is mainly because HESO serves as a non-profit program aiming to reduce energy usage, while the betting industry makes profits through wagering.
- *Scheming proper feedback frequency and HESO's duration*
  Feedback, as a positive 'cue', contributes to residential energy saving, however, labor cost would rise when the feedback frequency increased. Since a slight difference (1%) of energy saving in terms of daily feedback and weekly feedback was found [32], weekly feedback is recommended for HESO's implementation. Extending the duration until energy saving habits have been formed is essential to prevent decay effect after the 'cue' removed. The duration of HESO is suggested to be at least two months, since statistics showed that while the time needed for habituation may differ in various contexts, it takes 66 days on average for human beings to develop a new habit [10].
- *Setting gradually increased reachable goals*
  Goal setting takes a great part in HESO's successful implementation. From the field experiment, we can find that the result of the two-stage of goal setting is promising. The ultimate energy saving goal needs to be reachable and the difficulty of the goals in a sequence is suggested to be gradually increased. Only when the goal is accepted by participants, difficult goals lead to higher energy saving performance. If the goal is unreachable, it will cause dissatisfaction rather than motivation to households [87]. Once households' confidence, the motivation of energy saving and energy saving behaviors are well adapted under the initial goal, a more challenge but still accessible goal can be set to them. Specifically, the initial goal can be 'reducing energy consumption by 5% and then the goal can gradually increase to 10% or higher' in the following stages. It is worth noting that no significance was found between household initial energy consumption and their goal achievement. Therefore, the rule of setting gradually increased goals is applicable to all participated families no matter they have high or low energy consumption baselines.

7. Conclusion

This study presented the development of an innovative household energy saving intervention - HESO. It is likely to be the first study in the literature to provide the framework of an option-based cost-efficient household energy saving intervention and preliminary assessment of its effect on household energy saving. It was found that HESO has a positive effect on encouraging home electricity conservation. The results showed that the estimated effect of HESO on household energy saving was 8.18% (within 2 weeks) with the energy saving goal of 5%, and 12.56% (within 2 weeks) with the energy saving goal of 10%. The saving amount is equivalent to S$ 56.13 million (USD$39.85 million) per year with a 5% energy saving goal for all four-person households in Singapore [16]. Through the systematic equilibrium of HESO, the intervention can achieve cost-efficiency, which alleviated the fiscal burden of issuers while reducing household energy usage. Key determinants of HESO's successful implementation include information, credibility, and liquidity management from regulators' perspective. From the issuers' perspective, the design of incentive and cost, stimulus' duration and frequency, as well as the achievability of goal setting is essential to ensure successful implementation of HESO.

This study has contributed to proposing and validating the effectiveness of an innovative market-based intervention for energy saving in residential buildings. It demonstrated that marketized intervention has its advantages of cost-efficiency in the field of household energy saving. A better understanding of the market-based strategies and occupants' energy consumption changes will help to achieve energy saving with less financial cost in practice. Successful promotion and implementation of the marketized intervention require regulators and issuers to leverage their expertise, such as managing cash-flow liquidity and well balance reward and premium in order to achieve systematic equilibrium.

Although this study has made progress on developing a more comprehensive and cost-efficient framework of household energy saving intervention, it has a limitation in the research scope. This study only focused on public housing in Singapore without considering other housing types, such as condominium or detached houses. Therefore, the future study may consider to expand the research scope to various housing types and then to assess and compare the effect of HESO on energy saving and households' energy behavioral changes in different scenarios.

CRediT authorship contribution statement

Qian Xu: Methodology, Data curation, Writing - original draft. **Yujie Lu:** Conceptualization, Methodology, Resources, Funding acquisition, Project administration. **Bon-Gang Hwang:** Resources, Investigation. **Harn Wei Kua:** Resources, Validation, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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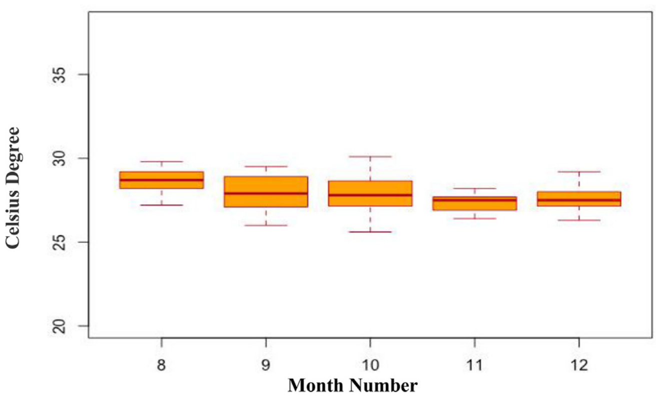
Appendix A. Historical daily temperature in Singapore (August to December 2018)



(Source: http://www.weather.gov.sg/climate-historical-daily/)

http://www.weather.gov.sg/climate-historical-daily/

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