Assessing the Residential Energy Rebound Effect by Means of a Serious Game

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Abstract. Residential energy efficiency improvements often have a smaller effect than expected. Although there is agreement on the existence of this effect, called the rebound effect, there is no agreement on the size of the effect. The objective of this study was to investigate the potential of using serious games to assess this effect. We used a game in which participants play home owners who manage their households in terms of energy consumption. Results of experiments with 50 players showed signs of the rebound effect when players with a low efficiency house reduced their energy consumption more than players with a high efficiency house. In addition, some issues related to previous studies were addressed, such as the possibility to perform an ex-ante assessment and to conduct the study in a controlled environment. Calculations of the size of the rebound effect depended on the approach used to determine the expected effect and showed differences between appliances.

Keywords: Rebound effect · Energy savings · NRG game
Game as a research instrument

1 Introduction

Improvements in household energy efficiency often do not lead to the energy savings which are expected. If energy efficiency is improved by 10%, one would also expect energy consumption to be decreased by 10%. However, due to the rebound effect, energy consumption is not reduced by that same percentage. Although there are different definitions in the literature, the following definition is explanatory and clear: "The rebound effect is the extent of the energy saving produced by an efficiency investment that is taken back by consumers in the form of higher consumption" [1, p. 2].

Figure 1 illustrates how the rebound effect works in household energy consumption [2]. First, technical improvements produce a more comfortable indoor environment and reduce the energy use. Second, this energy use reduction increases the disposable income which, together with a more comfortable indoor environment, produces an increment of the household lifestyle. Finally, a better lifestyle with more disposable income produces extra energy consumption (either in the same energy service

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producing a direct rebound effect, or in other energy services producing an indirect rebound effect). The latter partially offsets the initial energy reduction. This process of offsetting initial energy savings is called the rebound effect.

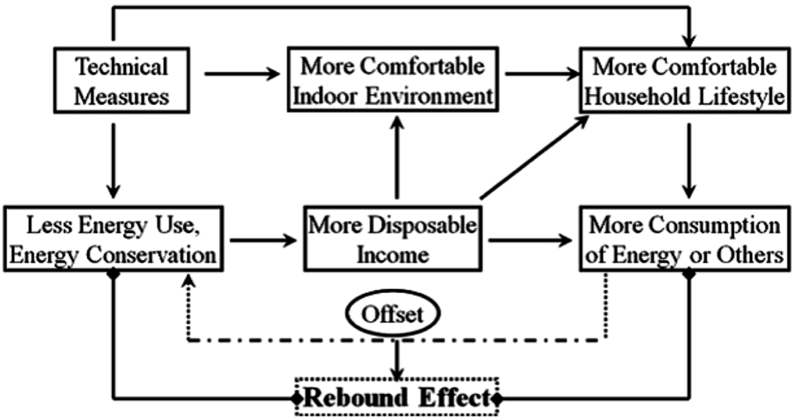

Fig. 1. Formation process of the rebound effect. (Source: [2].)

The rebound effect has been widely studied and analyzed (see [3–6], among others). Although the scientific community agrees that the rebound effect is true and can be measured, the size of the rebound effect is unclear since different scholars have calculated and measured different magnitudes of the effect [3–5].

Four main methodologies have been used in previous studies to measure the rebound effect: econometric studies of historical data, quasi-experimental analysis, direct surveys, and benchmarking techniques. One of the reasons why the extent of the rebound effect is unclear is that previous attempts to measure the rebound effect have some methodological issues [6–8]. Econometric and quasi-experimental studies provide ex-post information. In such studies it is difficult to isolate the rebound effect from other effects. Direct surveys suffer from biases as they do not rely on independently observed behavior. Benchmarking depends on data collected in other studies which suggests that there is not an exact fit between the studies and the objective to estimate rebound effects mainly due to socio-economic differences between the groups under study.

Serious games have a number of advantages compared to the studies above, in that in a game: variables can be controlled, an ex-ante analysis can be done, and a control group can be added. However, there are not only advantages to using a serious game. Since we are working with a representation of the real world, the applicability to the actual context is always an issue. Additionally, developing and using serious games is time-intensive which in practice limits the realism of the games used and the representativeness of the studies using serious games.

In this study, a serious game will serve as a laboratory environment to assess the rebound effect. This research aims to address the methodological problems identified in previous research and investigate the potential of using a serious game to assess the rebound effect.

The remainder of this paper is organized as follows. In Sect. 2 the game which is used to assess the rebound effect and the experimental setup are explained. Section 3 provides the results of the assessment and Sect. 4 concludes the paper.

2 Using the NRG Game to Assess the Rebound Effect

2.1 The NRG Game

The serious game which is used to assess the rebound effect in this study is called the NRG game. The NRG game was originally developed to test the influence of different interventions, such as information, feedback, discounts and subsidies, on energy conservation in households. The NRG game simulates the basic decisions households make regarding energy consumption.

The players' objective in the game is to manage their household in terms of energy consumption. Players must pay gas and electricity bills, can buy new appliances, produce energy using solar panels or wind turbines, sell appliances to get some money back, increase thermal or electric efficiency by investing in thermal insulation or smart meters, and so forth.

The main screen of the game is shown in Fig. 2, which shows the house a player has. Players can navigate through their house, and during the course of the game money becomes available to spend in order to simulate the income people would receive in real life.

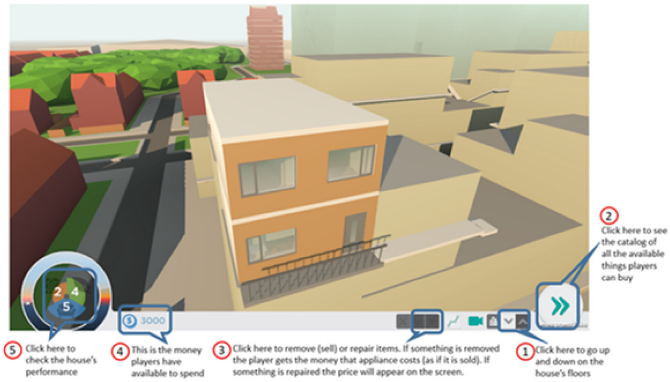

Fig. 2. Screenshot of the main screen of the NRG game.

The players can see a catalogue containing all available appliances that can be acquired (Fig. 3(a)) and they see the extent to which appliances are luxury and eco-friendly (Fig. 3(b)). The higher the luxury level of an item, the more expensive it is and the more comfort it adds. The higher the eco-friendly level of the item, the more expensive it is and the less energy it consumes. All (types of) energy consuming appliances in households are covered in the game with realistic relative performance and costs.

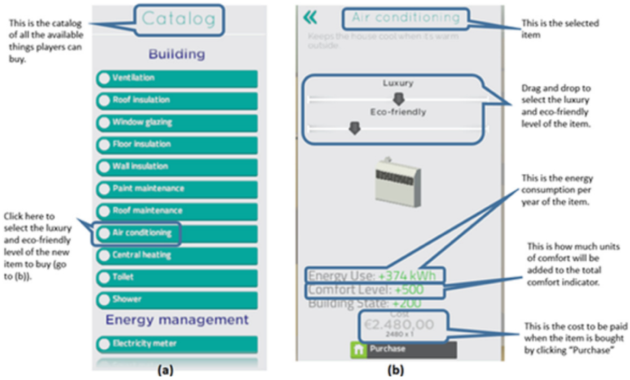

Fig. 3. Screenshot of part of the item catalogue in the NRG game.

After each round, players can monitor their performance in the game: their energy consumption, their energy production (if they decided to produce energy), their total comfort level, the condition of all the appliances and furniture they have in their houses, the total money they spend on electricity and gas, and the annual income they receive.

After players make any decision in the game, the choice they have made is stored. Specifically, the game stores the following information: the appliance, the comfort and eco-friendly level selected by the player, the money paid (received) after the purchase (sale), the money left in the player's budget, the total energy and gas consumption in the house after the decision, the money the player will have to pay at the end of the round for energy bills, and the round of the game in which the decision was made. This information is used to analyze the players' behavior and way of thinking regarding energy consumption.

2.2 Using the NRG Game to Assess the Rebound Effect

For the purpose of this study, we modelled two types of houses in the game. The only difference between these two houses is the energy efficiency level. One is called a "low efficiency house" and the other one a "high efficiency house". Players are randomly assigned to one of these houses. We observed and analyzed whether these two different but comparable groups of people behaved differently in the game. The "high efficiency" house represents a house with improved energy efficiency and the "low efficiency house" represents a house in which energy efficiency has not been improved.

Players were asked to follow three steps to complete the experiments. First, they were asked to answer a pre-game questionnaire to understand their socio-demographic characteristics and their real life behavior regarding energy consumption. Second, they were asked to play the NRG game for 45 min on average, in which they played 10 rounds of the game, simulating 10 years. Each player started the game with the same amount of money, which was available for buying new appliances, new thermal insulation or new devices to increase energy efficiency. The available catalogue for buying new devices contains 97 different appliances (this includes TVs, HiFi systems, washing and drying machines, movement sensors for reducing energy consumption, air conditioning, solar panels, wind turbines, different types of insulation etc.). After each round (i.e. each simulated year) players received an annual income that simulated the average annual amount of money people spend on electric appliances or energy efficiency solutions. The one and only instruction players received was to play the game as they would do it in real in life. Round by round, players had to pay their energy bills according to the energy consumption they had in that specific round. That money for paying bills was automatically deducted from the income players received after each round. Players used different strategies to manage their energy consumption in the game. Some players preferred to increase their comfort level in their virtual houses by buying luxurious appliances without taking care too much of their energy consumption, while others preferred to reduce their energy consumption by buying energy efficient appliances in order to spend less money on their energy bills after each round. All the decisions players made to manage their energy consumption were stored during the game for further analysis. The main idea was to compare how the two different groups of players (who received a house with a different initial energy efficiency) behaved throughout the rounds.

The third and final step was to answer a post-game questionnaire about their impressions of the game and the strategies they used while playing the game. From all that information (the questionnaires and the game itself) it was possible to investigate each group of players according to their decisions. If the two groups of players behaved significantly different with respect some of the defined KPI's we could infer that receiving a house with a certain initial energy efficiency affected their behavior during the game.

This experimental setup is different from a real before/after analysis in which the energy efficiency would have been improved at a certain point in the game and we investigate the behavior of players after it has been improved. The reason for this setup is rooted in the duration of the experiments. If one player is exposed to efficiency improvements in the middle of the game, there may not be enough time left in the game to properly analyze the impact of the efficiency improvement. If we can analyze the impact of this stimulus from the beginning of the game, the results may be richer and more conclusions may be obtained.

The low efficiency house group is used as a control group for the analysis, since they did not start with an "improved" energy efficiency house. The actual savings consist of the difference between the consumption of the low efficiency group and the high efficiency group (as this is what the high efficiency group saved).

The two types of houses have the same appliances at the beginning of the game and the only difference is the efficiency level of those appliances, resulting in a different energy consumption. Since the NRG game also gives an indication about the comfort level of players, this index must initially be equal in both types of houses. In doing so, the possible differences in the energy consumption of the two types of houses throughout the game is caused uniquely by a different initial energy efficiency level.

Fifty participants took part in the experiments of which 65% were students and 35% were (self) employed, 64% of the participants were male and 36% female, 15% were home owners and 85% lived in rented accommodation. These socio-demographic characteristics may have influenced the way participants behaved when consuming energy, which may limit the representativeness of the results.

3 Results

3.1 Presence of the Rebound Effect

Over the course of the game, the energy consumption of the two groups showed that the low efficiency houses group decreased their average energy consumption more than the other group, up to the point that in round 10 they consumed, on average, less than the high efficiency houses group (see Fig. 4), although the difference at the end is not statistically significant.

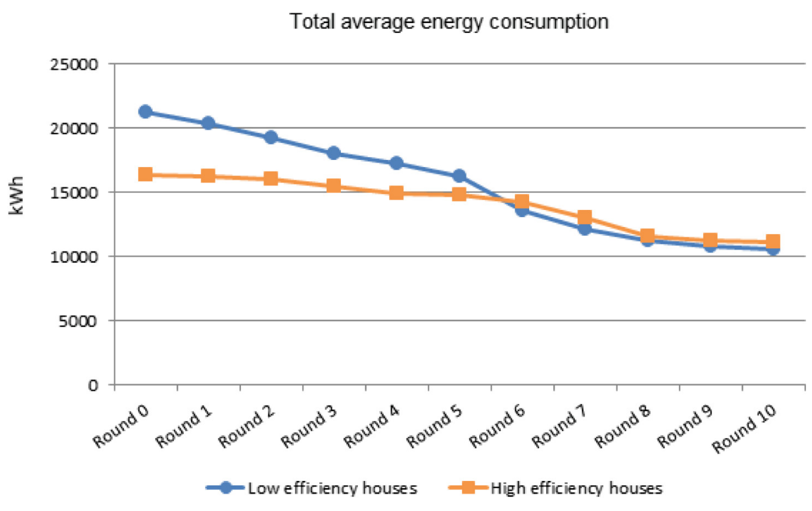

Fig. 4. Total average energy consumption per group per round.

The comfort level (Fig. 5) did not show significant differences between the two groups from round 1 to round 5 (both groups started at the same comfort level). However, from round 6 onwards, the comfort level showed significant differences between both groups. After finishing the game in round 10, the high efficiency houses group had increased their total comfort level by 16% on average, whereas the low efficiency houses group had increased their total comfort level by 4% on average.

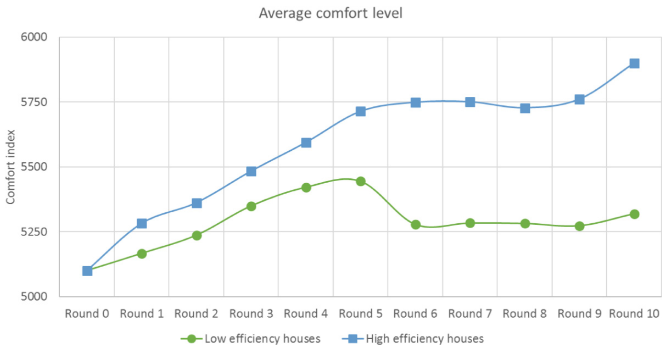

Fig. 5. Average comfort level per group.

Different patterns are observed for different types of decisions that can be made by players. With regard to purchasing energy management devices (any device that can reduce the overall consumption of a house, such as smart meters, movement sensors, stand-by-killers, or insulation), the average reduction of the total energy consumption can be seen in Fig. 6.

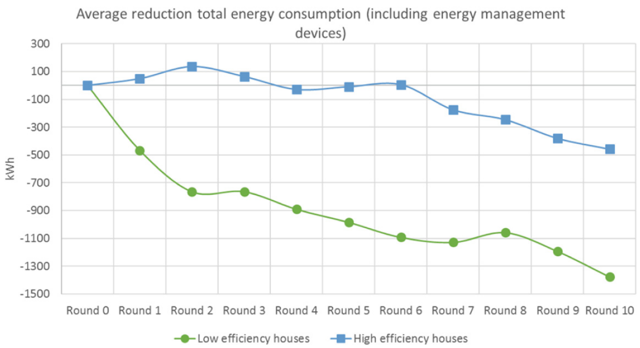

Fig. 6. Reduction of total energy consumption by including energy management devices.

The group with the low efficiency houses reduced their energy consumption more by including energy management devices than the high efficiency houses group. There is a significant difference in terms of the reduction of energy consumption between the two groups.

In Ref. [9] other decisions players made are analyzed in order to investigate if both groups significantly differ in taking one action more than the other group. For example, both groups did not show any significant difference in the decision to buy energy production devices (wind turbines/solar panels). However, when the decision of selling or getting rid of appliances was analyzed, the behavior showed that the low efficiency group got rid of more appliances than the high efficiency group, in a way to reduce their initially high energy consumption.

It is also interesting to note that from the post-game questionnaire it became clear that in the game significantly more people invested in energy production devices than in energy management devices, whereas energy management devices are more economically profitable. The latter shows that participants were more influenced by their own previous knowledge of the appliances than the information given in the game, somehow replicating what may happen in real life when consumers show irrational behavior when making a decision.

3.2 Calculation of the Rebound Effect

The differences between the two groups of players can be used to estimate the size of the rebound effect, which we do according to Eq. (1), which follows directly from our definition of the rebound effect [8].

$$r = ((e - a)/e) * 100 \tag{1}$$

Where r is the rebound effect, e represents the expected savings and a represents the actual savings.

However, we first need to determine actual and expected ‘savings’ in order to be able to apply the equation. The actual savings consist of the difference between the consumption of the low efficiency group and the high efficiency group (as this is what the high efficiency group saved).

In order to determine the expected savings we need a base case scenario. The base case scenario represents the behavior of the high efficiency houses group if the rebound effect was zero (note that this is not the same as the control group which is the low efficiency group). In other words, the base case scenario can be interpreted as the lowest energy consumption the high efficiency houses group could have had (the situation in which no energy savings are lost due to the rebound effect). Two different ways to define the base case scenario were implemented, one taking into account that that the high efficiency houses group has less opportunity to improve their energy efficiency since they are already highly efficient, and one without considering this difference in the opportunities to improve energy efficiency. Calculations using both approaches are discussed in [9]. The two approaches to calculate the base case scenarios showed similar behavior. The results for the (simplest) approach in which they have the same possibilities for reduction are shown in Fig. 7.

The dotted (green) line is the base case scenario and shows what reductions the high efficiency group could have achieved if they had reduced their consumption in the same way as the low efficiency group. For this reason the dotted line is parallel to the low efficiency (blue/top) line. We can see that the high efficiency houses (orange line/line which starts at same point as dotted line) in the game do not decrease their energy consumption to the same extent as could have been expected (dotted line). For each round the rebound effect (Eq. 1) may be calculated and the results are shown in the black line in Fig. 7, with the related axis on the right hand side.

When we regard individual rebound effects of the most energy consuming appliances in households, e.g. central heating, shower, refrigerator, the results differ from the overall rebound effect and also show differences between the two approaches to calculate the base case scenario [9]. The results show that the way the base case scenario is calculated is crucial for the final calculation of the rebound effect.

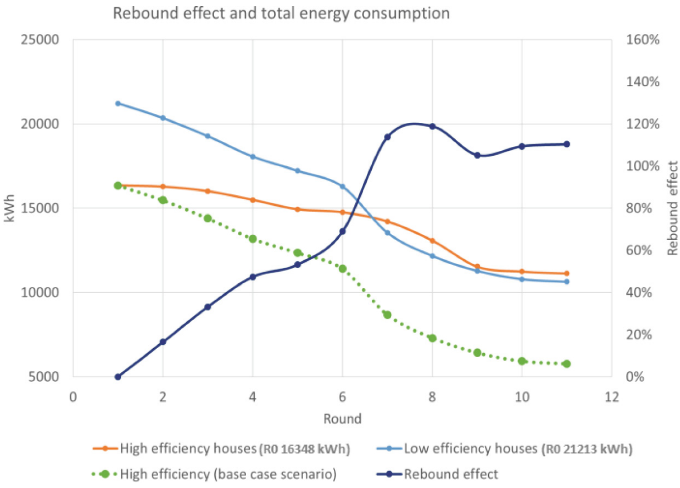

Fig. 7. Illustration of rebound effect calculation. (Color figure online)

With regard to Fig. 7, we conclude that the game enables us to calculate a rebound effect, but the number as such is very sensitive to the approach to determine the expected effect (base case).

4 Conclusions and Discussion

The results of the experiments allow us to draw some initial conclusions about the presence of the rebound effect in the game. If we take a look at the total energy consumption, we can see that the initial difference between the groups diminished over time. The low energy efficiency houses group managed to reduce their energy consumption more than the high efficiency houses group. With respect to the comfort level, we saw that in the later rounds, the high efficiency houses show a significantly higher comfort level than the low efficiency houses. This is explained by the fact that the high efficiency group had more money to spend due to their lower initial consumption, and thus lower energy bills. As a result, this group had the opportunity to buy more appliances that increased their overall comfort level than the other group. We also found that the group with the low efficiency houses reduced their energy consumption more by including energy management devices than the high efficiency houses group. Calculations of the size of the rebound effect depend on the definition of a base case and showed differences between appliances, confirming that the existence of one single rebound effect size should not be the focus of a study aiming to assess the rebound effect.

The objective of this study was to investigate the potential of a game to investigate the rebound effect. Using the game, we were able to conduct an ex-ante analysis and compare groups in a controlled setting. However, there were also some limitations which could be addressed in future research. The modified before/after setup may have influenced the outcome, since there was no change in efficiency within groups during the game. The post-game questionnaire also indicated that the realism of the game still requires some attention, partially because the way the game is set up does not allow players to change the real usage of appliances and it is assumed that appliances have a constant energy consumption.

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