HELPING INHABITANTS IN ENERGY SAVING AND GETTING INPUTS FROM USAGE FOR ECO-DESIGN: COOKING CASE STUDY

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Abstract

Inhabitants use energy to perform various activities of daily life in the private sphere i.e. the household scope. The activities they undertake are stochastic in nature and difficult to predict. Moreover there is a significant difference between real and theoretical uses of eco-designed products. It is therefore necessary to address the issue of measuring the real energy consumption of the inhabitants in order to identify their behaviour and decrease their environmental impact. In this paper we present an experimental study focusing on kitchen perimeter and cooking activity with two objectives: (1) ordering 20 advices to send to people by considering the perceived difficulty of practicing them and (2) identification of practice difficulties of eco-gestures by experience feedback. The aims are to get design inputs by increasing the difficulty of the activity and to identify needs related to a "weak" product design and consequently a user need to (re)design products for sustainable outcomes. Despite a low sample of 9 subjects, we get significant results allowing us to define a re-usable advices order and identify two real design needs from user feedbacks validating our approach.

Keywords: Human behaviour in design, Ecodesign, User centred design, Gamification

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Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 21st International Conference on Engineering Design (ICED17), Vol. 1: Resource-Sensitive Design | Design Research Applications and Case Studies, Vancouver, Canada, 21.-25.08.2017.

1 INTRODUCTION

The requirements for performance and durability for the construction of low energy buildings complicate the building design process. A key determinant of energy performance is the occupants' behaviour (Zaraket, 2014). Indeed, occupants use energy to perform various activities of daily life. We can talk about energy use in the private sphere i.e. the household scope. Most of the complex processes that occur in buildings result from human behaviour in a dwelling. The activities they undertake are stochastic in nature and difficult to predict (Zaraket, 2014). Moreover there is a significant difference between real and theoretical uses of eco-designed products (Chapotot et al., 2011) (Abi Akle et al., 2013). It is therefore necessary to address the issue of measuring the real energy consumption of the inhabitants in order to identify their behaviour and decrease their environmental impact.

To do this, we propose to use a gamification process through a connected game as a window on the private sphere of inhabitants/users. This study is developed in the framework of a European Union's Horizon 2020 project called GreenPlay. This project is motivated by several issues. First it fulfils the objective of Europe, namely a reduction of energy consumption by 30%. But also, the aim is to look through the game to monitor the real uses of the inhabitants in their private sphere. This line of research has a dual interest, first to identify levers to change behaviour but also to be able to identify decision variables for the future building ecosystem's design (building, household appliances and services, etc.). Here, decision variables are considered in a broad sense and refer to user-centred-criteria to take into account e.g. during manipulation of design performance variables. Figure 1 illustrates the scope of our project and the research questions in the overall project.

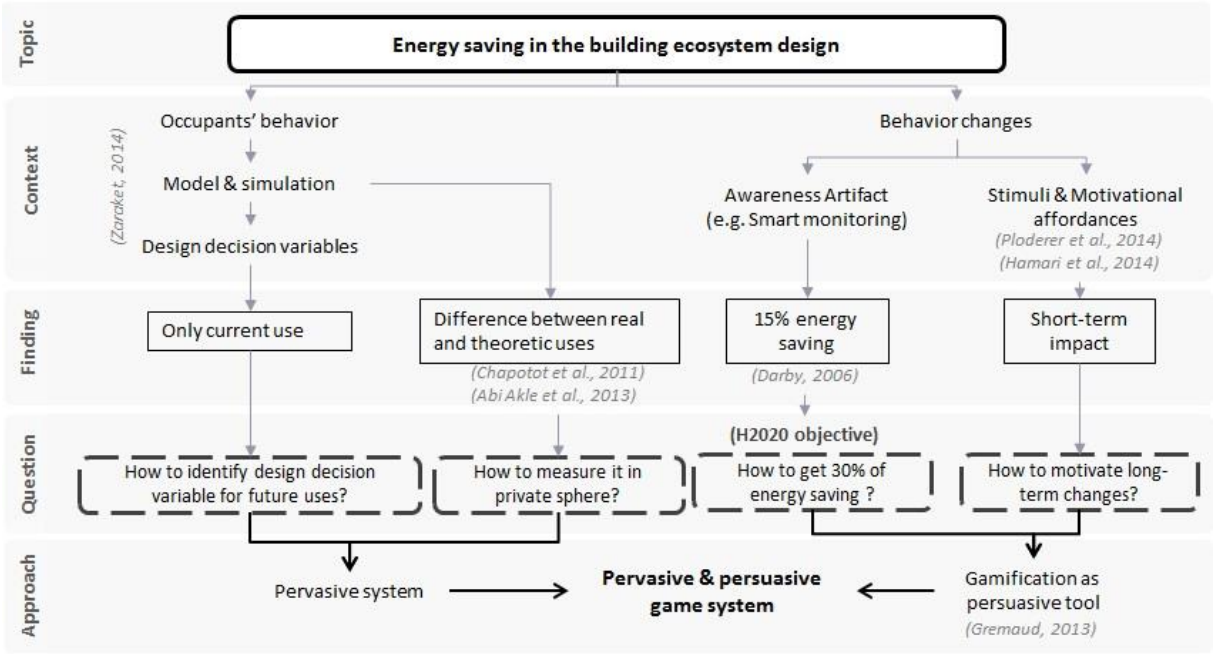

Figure 1. Scope of our research project

The solution developed in our project therefore includes a software part with the pervasive and persuasive game system and a hardware part with electricity consumption sensors. The solution is deployed in 164 households for an experimental period of one year. As such we believe it is necessary to test the feasibility upstream i.e. the possibility to answer our first research question: **How to identify design decision variable for future uses?**

Thus, in this paper we present an upstream experimental study with two objectives, linked to the European project:

- First, order advices / eco-gestures to send to participants by considering the perceived difficulty of practicing them. The aim is to get design inputs by increasing the difficulty of the activity.
- Secondly, the direct identification of practice difficulties of eco-gestures by experience feedback. The aim is to identify difficulties related to a "weak" product design and consequently a user need to (re)design the appointed product for sustainable outcomes.

The study presented in this paper focuses on kitchen perimeter and cooking activity with 20 eco-advice / eco-gestures. Despite the low panel of 9 testers we got significant results which allowed us to identify two design needs and validate our approach for identifying design decision variables for future use.

2 USER-CENTERED DESIGN TO CREATE SUSTAINABLE OUTCOMES

According to the work of Wever et al. (2008), we identify two approaches in user-centred design to create sustainable outcomes. The first is about changing consumer behaviour by the design of the product and the second is about designing products to adapt to the way people actually use the products. One relevant method falling under the first approach is the "Design with Intent" or "DwI" methodology (Lockton et al., 2010). It is a set of design models to explore the interactions between design and behaviour of people, through products, services and environments. This method aims to give practitioners a more balanced approach to design and behaviour, including the complexity of everyday human experience. By extension DwI method focuses on how the designer thinks rather than the user do it. On the other side, designing a product to align with how people actually use it may result in less negative impacts by eliminating redundant or missing functions, but still fulfilling the overall function desired by consumers (Komeijani et al., 2016). For us, user-centred design to create sustainable outcomes involves the analysis of the use phase. Indeed, the use phase and consequently the user, plays a key role in product performance (Sanyé-Mengual et al. 2014). However, as pointed out by Kota et al. (2012), use is seen as having the poor relation in the environmental analysis. This finding is highlighted by data that are simplified and defined arbitrarily. One proposed interpretation is the difficulty of taking into account the diversity of patterns of use and users. More recently, major efforts are brought in the work of (Domingo and Rio, 2016) that proposes a five step method to link the use stage with product design models of usage. They improve link between usage information and the environmental expert's explicit knowledge on usage.

Another important point is the "eco-designed product in the wrong direction". It has been shown that focusing on the use laundry detergents that are eco-designed provides no environmental gain (Chapotot et al., 2011) (Abi Akle et al., 2013). These two studies reveal that theoretical and real uses of laundry detergent are very different at the advantage of the regular detergent. Thus, the user behavior allowed highlighting eco-design "badly mastered" and the importance to engender a usage centered eco-design approach. So we have to take into account in our approach the difference between real and theoretical uses of (eco-)designed products. In addition, our study focuses on the uses in homes and confronts us with the difficulty of the "private sphere" effect.

Facing these issues our proposal is to use a game to monitor real use or behaviour. Our approach is closed to the method of Raghupathi et al. (2015) who present a customer sentiment appraisal from user-generated online product reviews.

Then we propose to use "big data" generated through the game with a great advantage of controlling the dispatch of stimuli (i.e. advices) to identify user's needs. Before implementing the fully developed software solution, we propose to test the feasibility of the approach.

3 ENERGY FEEDBACK & GAMIFIED APPROACH FOR ENERGY SAVING

The idea of using smart meters, real-time feedback, or variable tariffs to influence energy use by private consumers is not recent. Research shows that direct feedback in home displays could save up to 15% electricity (Darby, 2006). However, as stated by Paetz et al. "although providing information and feedback is a precondition, it may not be sufficient on its own" (Paetz et al., 2012). Then, the use of games appears in the 2000s with first serious game type as for example Professor Tanda (Chamberlain et al., 2007). The primary objective was to increase the awareness of people then let them reduce their electricity consumption. One difficulty of this game is that consumption data are not connected to the game and users are required to enter them manually. Thus the pervasive games appear to reduce electricity consumption. Pervasive games are often referred to games that extend beyond the traditional interface into the real world (Nieuwdorp, 2007). Nine projects working on pervasive and persuasive gaming for energy conservation are identified (see Table 1). All of these games use the principle of "reward" as encouragement but they differ a lot considering functionalities: advice generator, quizzes, use of cooperation and/or competition and video game. All projects are considered games but few of them include video or computer games. The advantage of gamification is that behaviour change and thus energy saving is stimulated by rewards but also by the social interaction through cooperative

challenges. The state of the art presented in the Table 1 shows that solutions enable a reduction in energy consumption as the solution is used. However, energy saving does not persist when game ends.

Table 1. State of the art of projects proposing game for energy saving

Name	**References**	**Sample**	**Duration**	**Energy saving**
Power Agent	(Gustafsson et al., 2009a)	6 players (and their family)	10 days	After effort (1h): ~34%
				During Game period: ~22%
			57 days after	After the game: ~0.2%
Power Explorer	(Gustafsson et al., 2009b)	15 participants (12-14 years old)	1 week	During game: ~16%
			10 weeks post exp.	14% (not statistically significant)
Energy Life	(Björkskog et al., 2010) (Gamberini et al., 2012)	24 participants = 8 households	3 months	Null. They observe decrease of the accesses
Gaea	(Centieiro, 2011)	No quantitative but usability studies		
LEY!	(Madeira et al., 2012)	Focus on architecture game design for environmental awareness		
Energy Battle	(Geelen et al., 2012)	17 households (2-5 persons)	4 weeks test	24%
		10 households	4 weeks after	Very variable values according to households
Energy Explorer	(Wells et al., 2016)	Focus on methodology and game description		
EnerGAware	(Casals et al., 2016)	Focus on game description		
GreenPlay	ongoing	152 households with sensors	1 year	Objective: 30%

Finally, there are differences between games and smart feedback monitor. The display of consumption, quizzes and advices are also effective in gamification solutions. Thus, it is still necessary to manage the different advice. We have some indication about frequencies and time period of stimuli/ feedback sending (Fischer, 2008) but we do not know what order of sending advice is efficient. This issue is particularly challenging in our case of identification of user needs and design inputs.

4 PROPOSITION OF SOLUTION AND ISSUES

The proposal is based on a system perceived as a game by the user (because using element of game design). It allows to monitor real behaviour and possible long-term changes in the context of energy saving. The system is composed by sensors, a smart monitoring platform and the game as illustrated in Figure 2. The sensors installed at the user's home measure global electricity, heating, water heating and temperature. The sensors are linked to our system. This is a pervasive game i.e. eco-gestures in real life and thus electricity consumption reduction allows to earn points and evolve in the game.
The game part allows sending stimuli focused on specific activities as laundry activity, cooking activity or watching TV. In parallel it measures, with the sensors, if there are differences in the consumption data (reduction or increase). To monitor the behaviour and changes, stimuli are organized by activities and will be sent in distinct phases. Quizzes will also be sent at different times to collect feedback and to know, among other things, the (new) participants habits. A decision tree including the stimuli, the questions and the conditions of their dispatches is designed. The reliability of this model will be validated through a large scale experiment based on 164 households situated in France and Spain during one year.

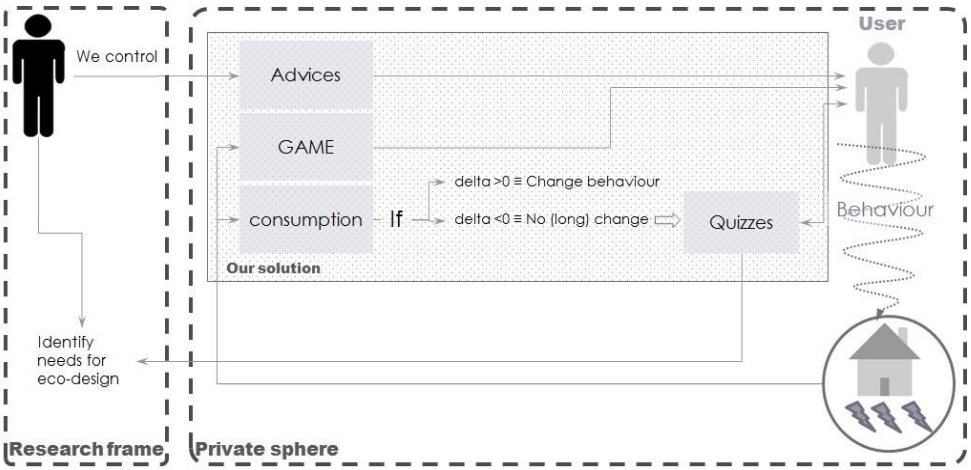

Figure 2. Our solution proposition

As previously mentioned, we believe it is necessary to test the feasibility upstream i.e. the possibility to answer the research question: How to identify design decision variables for future uses?
Therefore we design an upstream experimental study with these two objectives: (i) order advices / eco-gestures to send to participants by considering the perceived difficulty of practicing them and (ii) identification of practice difficulties of eco-gestures by experience feedback. Our study focuses on kitchen perimeter and cooking activity with 20 eco-advice / eco-gestures. We have selected the cooking activity because it is one of the activities that consumes the most energy, and energy consumption data for cooking activities by type of meal or appliance are very scarce (Wood & Newborough, 2003). The cooking activity is particularly stochastic in comparison to other activities in a home such as “laundry”. Indeed, there is no "cooking" process to follow but there are cooking situations. For example: With the "laundry", we all wear clothes and we wash them while with cooking: we all eat but we do not necessarily cook. Moreover, a large number of sources of electricity consumption (household appliances, equipment, robot, etc.) participate in these situations. We can find in a kitchen about 30 electrical sources that can have continuous consumption (e.g. refrigerator), frequent (e.g. coffee machine) or specific (e.g. electric mixer).

5 DESIGN EXPERIMENT

First, an approach that sends stimuli to encourage more virtuous behaviour, or more simply the achievement of eco-gestures, should address the issue of advice and their classification or ordering.
We selected 20 recommendations from a study of ADEME that list and explain some eco-gestures to be practiced within the perimeter of the kitchen in order to reduce electricity consumption (ADEME, 2015). The difficulty with the scheduling lies in the logic or coherent sending of advices. For example we could focus on the equipment, the energy gain, the frequency of the suggested task or the difficulty in practice of the eco-gesture, etc. According to our interest in usage and human behaviour, three ways of organizing eco-advices are identified: the frequency of practicing eco-gesture, the economic benefit of practicing eco-gesture and the difficulty of practicing eco-gesture.
It appears that the first two are objective and the last is subjective. Moreover, it is related to the will, the motivation of practice change and the ability of subjects to push back their comfort zone. Finally, we can list several ways to perceive the difficulty (Delignières & Famose; 1992):

- The perceived difficulty can be objective i.e. the difficulty is evaluated from an external point of view.
- The perceived difficulty can be assessed from a personal point of view i.e. knowing what we are able to do in our home every day.
- The perceived difficulty may be "altered" by considering the gain of the eco-gesture practice.

We choose to verify the perceived difficulty of practicing eco-gestures with experimentation.

5.1 Procedure

We split the session into 4 phases (see Figure 3). The first phase is composed by a questionnaire in order to get the subject profiles (age, gender, environmental awareness and cooking habits).

The phase 2 is divided in 3 steps of eco-advice sorting according to different modalities of perceived difficulty. The instructions given for each phase are as follows:

- Sort eco-advices based on their difficulty level of practice.
- Sort or change your ranking of eco-advices considering that you are going to perform them.
- Sort or change your ranking of eco-advices considering the gain i.e. the economy that can bring the practice of each of them.

Thus we begin by a "simple" sorting of difficulty level, then sorting by considering the personal difficulty (i.e. the practice) and finally sorting of difficulty by considering the ratio of "gain-effort".
The phase 3 begins by suggesting the participant to choose one advice among the 20 in order to try to practice the eco-gesture. The proposal is open and the subject has the right to reject and to stop the experiment. If the participant agrees, we take a new appointment the following week.
The fourth phase is composed by a questionnaire in order to get experience feedback about the week of practicing the eco-gesture.

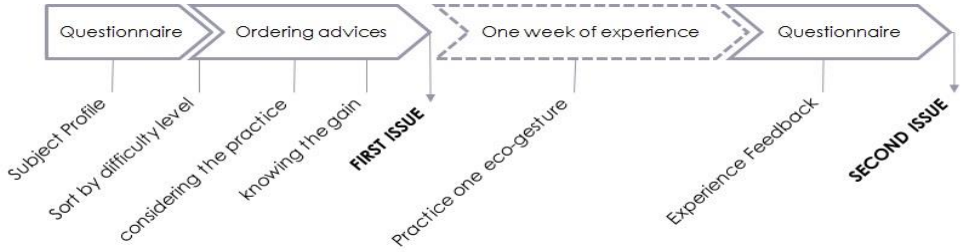

Figure 3. Procedure of the experiment

5.2 Material

We choose to use twenty advices from ADEME (2015) which we add the gain/economy of practicing eco-advice (Familles à énergie positive, 2011). The economy is presented as an index ranging from 1 to 3, 3 being the maximum gain. The list of advice and their gain is presented in the Table 2.

Table 2. Advices used during the experiment

Gain	n°	Advice
2	1	Use the dishwasher instead of hand washing
2	2	Do not turn your dishwasher on if it is not filled completely
1	3	Above 3 mm of frost, the freezer overconsume, remember to defrost
2	4	Avoid wastes and do not open the oven door while it is on
3	5	Avoid using the microwave to defrost your food, leave them at room temperature
2	6	Take time and defrost food in the refrigerator
1	7	Check the temperature of your refrigerator, 5 ° C is the "standard" temperature
1	8	Adjust the volume to your needs: your kettle has a capacity of 1.5L but your teacup 30cl, do not put more in the kettle
2	9	Avoid wastes and use pans adapted to the size of hotplates
3	10	To reheat the meal, use the microwave rather than the oven
1	11	Use the heat inertia : turn off the oven/hotplates few minutes before the cooking time
2	12	Before you put water into a pan to cook, do it boil in the kettle
3	13	Remember to cover your pans while cooking, it goes faster and you save energy
1	14	Winter, after using the oven, enjoy the warmth, opens the oven and cut the kitchen radiators
2	15	Wait the meal is well cooled before putting it in the refrigerator
1	16	Avoid repeated openings of the refrigerator
2	17	Consider the arrangement of your kitchen, the refrigerator should be located away from sources of heat (oven, hotplates, radiators or direct sunlight)
1	18	Cover liquids and wrap the vegetables placed in the refrigerator
1	19	When you store your products in the refrigerator, remember to let air circulate
1	20	Clean grill in the back of the refrigerator (2 times per year)

To stay in a playful theme, eco-advices were transformed into a card game. The cards are available: http://these.aaa.alwaysdata.net/grilleecogesture/cardstoprints.pdf . The game is titled "Grill your eco-gestures" and each card is an eco-advice. We find on the front of the card the eco-advice, the card game logos and the gain index (3 bars). On the back of the card is presented an illustration of eco-advice. In Figure 4 is presented the card of the advice n°1.

Figure 4. Card of the eco-advice #1. Front card on the left and back card on the right

6 RESULTS

For the experiment, we recruited 9 people, 4 men and 5 women. We observe in our sample that on average men are 42.75 and women are 41.2 respectively with a standard deviation of 5.80 and 8.39. According to the first questionnaire 44% of the sample says cooking every day. We notice that none of the men in the sample cook every day (against 44% for women). However, the trend is reversed for the knowledge of electricity consumption sources in the kitchen. Indeed, 75% of men have completely or high knowledge of the electricity consumption sources in their kitchen against 40% for women.

6.1 Ordering advice: difference between sorting

For all realized hypothesis tests, we set a significance level of $\alpha = 10\%$.
We have 3 groups of measures (i.e. sorts performed) and a sample of n = 180 (i.e. 9 subjects * 20 advices). The groups are paired (within approach) because for each sorting the same advice is assessed. The variable is ordinal (i.e. perceived difficulty), thus we perform a Friedman test. We obtain a significant result: Qobs=18.5 and p-value= 9.61E-5. So we perform Wilcoxon Signed-Rank tests for a post-hoc analysis:

- Sort1 vs. Sort2: W=279 and p=0.0002
- Sort2 vs. Sort3: W=-65 and p=0.0195
- Sort1 vs. Sort3: W=208 and p=0.0782

The results are significant. We observe that perceived difficulty (sort1) < perceived difficulty (sort2), perceived difficulty (sort2) > perceived difficulty (sort3) and perceived difficulty (sort1) < perceived difficulty (sort3). The perceived difficulty is higher when subjects consider the practice but it becomes less important when considering the economic benefit (i.e. gain).

6.2 Ordering advice: difference between advices

For this part, we seek a perceived difficulty difference between advices. For this part we only consider the sort3. We have 20 paired groups (i.e. advices) formed by n=9 subjects and the variable is ordinal: a scale of 1 to 3, 3 is the higher “difficult” level. We perform a Friedman test. We obtain: Qobs=67.29 and p-value= 2.58E-7. There is a significant difference between the 20 advices. So we have to conduct pairwise Wilcoxon tests. We present a summary of the Wilcoxon results in Table 3. The "1" in the table represent p-values less than α and the "0" are p-values superior to α.
To complement the results obtained with the Wilcoxon test, we propose to calculate the percentage of similarity(s) (Equation (1)) of each advice taken two by two. Beyond 60%, we consider that there is a high similarity of perceived difficulty of the advices. To calculate the percentage of similarity, we have:

- Let Ck the kth advice
- Pi : ith subject (n=9 subjects in our study)
- di(k) : the difficulty level of the kth advice giving by the ith subject let $\alpha i(k.l)$ such as $\alpha i(k.l)=1$ if $di(k) = di(l)$ else $\alpha i(k.l)= 0$ with $l \neq k$

$$s(k.l) = \sum_{i=1}^{n} \frac{\propto_i (k.l)}{n} \times 100 \quad (1)$$

We present a summary of the results in Table 3. Pairs of advice obtaining percentage of similarity higher than 60% are represented by an asterisk (*).Furthermore, we indicate in the second column of the Table 3 the index mean of perceived difficulty of each advice (represented on a scale of 1 to 3). Thus, the advices are classified from harder to easier (top to bottom).

Table 3. Test results comparing the perceived difficulty of each eco-gesture

advice	Mean	20	3	4	6	14	7	17	11	19	5	8	16	12	18	9	1	2	13	15	10
20	3		*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	2.89	*		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	2.22	1	1		0	0	0	0	0	0	0	*	0	0	0	1	1	1	1	1	1
6	2.22	1	1	0		0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
14	2.11	1	1	0	0		0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
7	2	1	1	0	0	0		0	0	0	0	0	0	0	0	0	0	1	1	1	1
17	2	1	1	0	0	0	0		0	0	0	0	0	0	0	0	*	1	1	1	1
11	1.89	1	1	0	0	0	0	0		*	0	0	0	0	0	0	0	0	1	1	1
19	1.78	1	1	0	0	0	0	0	*		0	0	0	0	0	0	0	*	1	1	1
5	1.78	1	1	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	1
8	1.78	1	1	*	0	0	0	0	0	0	0		*	0	0	0	0	0	0	0	1
16	1.78	1	1	0	0	0	0	0	0	0	0	*		0	*	0	0	0	0	0	1
12	1.67	1	1	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	1
18	1.56	1	1	0	0	0	0	0	0	0	0	0	*	0		0	0	0	0	0	1
9	1.44	1	1	1	1	0	0	0	0	0	0	0	0	0	0		0	0	0	*	*
1	1.44	1	1	1	1	1	0	*	0	0	0	0	0	0	0	0		*	*	*	*
2	1.33	1	1	1	1	1	1	1	0	*	0	0	0	0	0	0	*		*	*	*
13	1.22	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	*	*		*	*
15	1.22	1	1	1	1	1	1	1	1	1	0	0	0	0	0	*	*	*	*		*
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	*	*	*	*	*	

The most important results, that we observe, are the first 2 advices number 20 and 3 which are perceived as the most difficult to perform. They are also significantly different from all other advices and get a high percentage of similarity. It is particularly interesting to note that they are advices related to an activity of “cleaning” (see Table 2). In accordance with the perceived difficulty of the advice #3 "Clean grill in the back of the refrigerator", we may note, a design need for fridges.

In addition, it appears that the advices numbers 1, 2, 13, 15 and 10 are those that reveal the lowest index of difficulty but also with a high percentage of similarity between them. The discussion conducted with all subjects reveals that these advices are perceived as "easy" as they are already practiced by the subjects.

6.3 Feedback of the experience

All participants agreed to continue the experiment in trying to practice an advice for one week. However, one person does not come to appointments. So we have the experience feedback of 8 subjects. The experience feedback was noted based on a questionnaire. The interview aimed to discuss 5 points: (1) the achievement level of practice, (2) the practice of another advice, (3) The real difficulty of practice, (4) The difficulty compared to the perceived difficulty and (5) The wishes to continue. We present below the results.

- Achievement level of practice:

There are 6 subjects who fully or as much as possible practiced the advice against 2 who have a little or not at all practiced the advice they had chosen

- Practice of another advice:

There are 7 people who practiced an additional advice to the one chosen for the duration of the experiment. We believe that this result is related to the newness effect.

- Difficulty of practice:

There are 7 subjects who did not feel as difficult the practice of the advice against one person who says that he chose defrosting the freezer and "it takes time".

- Difficulty compared to the perceived difficulty:

5 subjects consider that the practice was easier than expected; one person finds that the level of real and perceived difficulty is identical and finally 2 people found that the practice was more difficult. We asked these two subjects to explain:

The first who chose the advice #19 "When you store your products in the refrigerator, remember to let air circulate" tells us that it was difficult to apply the advice because his/her family made the errand once a week and there is not enough space in the fridge to let air circulate.

The second who choose the advice #8 "Adjust the volume to your needs: your kettle has a capacity of 1.5L but your teacup 30cl, do not put more in the kettle" tells us that it was difficult to apply the advice because the minimum volume of the kettle is larger than the volume of a cup of tea. This feedback is a critical need for design because the current design of the kettle does not allow the practice of an eco-gesture.

- Wishes to continue:

Unfortunately, only half of the participants are ready to pursue the practice of advices. The half that does not continue being honest to admit "I would not do it" or "I can't be bothered". The other half feels motivated to continue because they are convinced of the economic benefits.

7 CONCLUSION

Through this study, we obtain significant results and present a re-usable advices order. In addition, we point out that our approach will make it possible to identify user needs to (re)design products for sustainable outcomes. From a small sample, we identify two real design needs: one for the kettle and the other one for the grill of the fridge. Finally, we believe there is a strong duality between (1) asking consumers to make efforts to reduce their electricity consumption and (2) asking designers to better design for more virtuous use. Indeed, it is necessary to clearly identify the needs and "pains" to translate them so that the designers are able to guide the users to reduce their consumption. Convinced that it is possible to reduce our energy consumption, we think it is the role of designers to create this world of possibilities.

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ACKNOWLEDGMENTS

We wish to thank all those took part in our experiment and Irati Malkorra who had created all artworks of the cards game. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 649621.