Introducing Smart Grids in Residential Contexts: Consumers' Perception of Smart Household Appliances

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Abstract— *A more energy efficient supply and demand in household settings is high on the agenda. Smart grids, smart meters, demand side management and smart appliances play a crucial role in this context. Many stakeholders are involved, but the exact role of the customer is often neglected. More specifically, his opinion, attitude, drivers or barriers towards new ways of energy consumption and energy management. This paper employs a user-centric perspective. It aims at mapping consumers perception of the possibilities of demand side management through smart household appliances. A quantitative survey was conducted among 500 households spread over Flanders, Belgium. In this paper, the results of this survey with regard to the respondents perception of smart appliances are presented. The Technology Acceptance Model was used as the theoretical framework to measure these perceptions.*

***Index Terms*—consumer behavior, demand side management, energy consumption, smart appliances, smart grid**

1. INTRODUCTION

SMART grids are a topic that is high on the agenda. They are the electricity network of the future, allowing an intelligent monitoring and/or controlling of electricity streams. In order to have an efficient energy demand management or demand side management whereby the energy use of different types of consumers can be adapted, the implementation of smart meters is strongly promoted by political as well as economic organizations [1]. In the debate towards a more energy efficient supply and demand in household settings, several ideas about smart meters and smart appliances come to the surface, ranging from alternative forms of billing to the implementation of washing machines that can postpone operating for energy efficient reasons.

In the current discussion about smart meters and smart appliances different kinds of stakeholders are involved: energy suppliers, political institutions, green parties, smart device manufacturers,… Often neglected though, is the exact role of the consumer, or more specific, his opinion, attitude, drivers or barriers towards new ways of energy consumption and energy management. In other words, if we want to change the energy consumption pattern and make it smarter, this should not only be done from a top-down perspective.

As a consequence, this paper employs a user-centric perspective. It addresses issues such as the effect of giving personalized feedback on energy consumption and refers to studies that have been conducted concerning a possible future implementation of smart meters and smart appliances. These two topics clearly demonstrate that a well-considered user involvement and communication towards this end-user are necessary for better energy demand management.

In this perspective, a more thorough study of the user remains indispensable, in order to gain insight in the willingness of consumers to accept different kinds of measures when it comes to smart metering and smart appliances in their daily life, so as to have an efficient user adoption in the future. This paper addresses this issue by describing in detail the set-up of a large-scale face-to-face user survey conducted from March 2010 until May 2010 in Flanders, Belgium.

2. THE ROLE OF THE USER

Effects of feedback on energy consumption

Households account for approximately 25% of the Belgian energy consumption. The largest part of this energy is used for the heating of the house, the rest is used for electric appliances and water heating. Therefore, energy efficiency measures regarding insulation and efficient use of electric appliances will become increasingly important in the residential sector. Mansouri-Azar et al. [2] found that a majority of the their respondents did not even know which of their electric appliances consumed most energy. At the time the research was carried out, the lighting, freezer and dishwasher were the most consuming appliances in the UK households. Nonetheless, most of the respondents named the washing machine in their top three. Thus, if people have no insight in the amount of energy their appliances consume, it is hard to reduce their energy consumption, or to expect an adequate change in behaviour from that user. To date, it is clear that this behaviour or use of electric appliances can (and needs to) be more energy efficient. To do this, one can give the consumer

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tons of information on how to save energy. Another way is to actively address them, giving important information on energy consumption while using the electric appliances.

Previous research (a.o. [3, 4],[5],[6],[7]) has shown that active feedback on energy consumption is effective to encourage households to take energy conserving measures. Van Raaij and Verhallen [8] distinguish three main functions of feedback:

(1) learning: the provided feedback gives the consumer information on the results of certain actions;

(2) habit formation: the feedback helps in forming certain new habits with regard to energy conservation. These habits should remain when the feedback is removed;

(3) internalization of behaviour: feedback helps to create new attitudes and habits that become embedded in a person's behaviour. These habits and attitudes will influence energy-related actions in situations where the feedback will not be present. In the following paragraphs we will discuss the major results of research that has been carried out in this area.

Brandon and Lewis [9] placed 120 households in 6 feedback conditions: (1) comparison of own household energy consumption to that of other households, (2) comparison of own energy consumption, on different moments in time, (3) financial values (information on consumption and costs), (4) environmental values (such as the relation between energy consumption and the effects on the environment, e.g. global warming), (5) leaflet presentation (information on energy saving measures) and (6) computer presentation of individual household data. A 7th group did not receive any feedback and served as a control group. A survey was also taken to gain insights on environmental attitudes, energy saving measures and socio-demographic information. The results showed that the computer group performed better than the other experimental groups. The energy consumption in this group decreased significantly compared to the control group: 80% of the households in the PC condition reduced their energy consumption significantly. In the other experimental conditions, the decrease was less significant. Ueno et al. [4] installed an energy consumption information system (ECOIS) at nine houses. This system measured electric power consumption for the house and for each home appliance separately at intervals of 30 minutes. The household members could access their consumption by means of a computer. As a result, the researchers found a 9% reduction in the household's power consumption. Also, the energy awareness that resulted through the feedback triggered a different behaviour towards other appliances besides those that could be monitored on the screen, which is consistent with Van Raaij and Verhallen's third function of feedback [8].

Consistent with these findings, Wood and Newborough [7] found that dynamic energy consumption feedback via smart meters and displays reduced the consumption by 10% up to 20% within the households that were monitored. They suggest that feedback can be given at best during or immediately after the use of an appliance. This way, the consumers are provided with immediate updates on their energy consumption patterns. Previous research [10],[11], has shown that this instant feedback is indeed very effective.

Direct feedback clearly has an impact on behaviour, especially in the case of direct feedback, provided at the moment of the use of an appliance, or by the appliance itself. The next paragraph focuses on these next generation electric appliances or "smart appliances".

Smart Appliances and Demand Side Management

A growing increase in the purchase of electric appliances causes a growing demand for energy in households. Inefficient use of these appliances causes a waste of energy. In the previous paragraphs we indicated the importance of energy feedback to inform the users on their behaviour, leading to a reduction of this energy wasting behaviour. Another way to reduce energy consumption is the application of demand side management. DSM can help reduce peak demand and energy consumption while still allowing for the same level of comfort within the household.

Key in this context could be the so-called smart appliances. These appliances are designed to work within smart grids. A necessity for the implementation of these applications is the availability of a smart meter in the house. Refrigerators, freezers, washing machines, clothes dryers and dishwashers are amongst the most energy consuming appliances used in households. Smart technology can help reducing their energy use. An example of the application of smart technology is the possibility to partly or completely switch off an appliance during its runtime without any noticeable consequences for the consumer. Block et al. [12] state that 50% of the energy use in homes is generated by appliances like refrigerators and washing machines. More generally, in all appliances that need energy, but are flexible in terms of the moment at which this energy is delivered, this kind of technology can be integrated [13].

However, the question here arises to what extent the consumer will allow interference of these machines into their life. While these applications of smart technology might be important to reduce household energy consumption in a substantial way, it is important to keep the consumer's attitudes and opinions in mind, especially in terms of their control over these, in a certain way, *self regulating* devices.

An important study that tried to discover the consumers' attitude towards these smart appliances is Smart-A (http://www.smart-a.org), supported by the European Commission under the 'Intelligent Energy-Europe' Program. It addresses in particular the issue of smart energy loads, determining the degree of possibility for smart appliances to adapt or alter their operation to variations in the regional and local energy supply, complemented with user acceptance research and economic modeling.

The study identifies some clear drivers and barriers when it comes to the use of smart appliances by customers and their willingness or flexibility to accept these kind of appliances [14] In general, by means of quantitative (survey) and qualitative (expert interviews, focus group interviews) user research in several European countries, the study reveals a high acceptance degree when it comes to the use of smart appliances, but the economic advantages are far more imperative than the ecological ones, and price-related issues such as ROI and purchase price are of major importance. Furthermore, the study also demonstrates that end-users are not always willing to change their daily pattern or habits. As to mention one simple and clear example: the respondents stress the need of short interruption cycles when it comes to washing machines, because the respondents do not wish to leave their wet laundry in the washing machine for hours. In addition, the respondents stress the need of self-control when it comes to the operation of these domestic smart appliances.

In light of the future developments when it comes to smart grids and smart appliances, the Smart-A project offers some interesting findings.

3. RESEARCH

Many studies, fragmented answers

The former paragraphs already demonstrated that users are an important target group when studying concepts such as smart metering or smart appliances. As literature shows, several studies try to grasp the customers' opinion and attitude about energy efficiency and/or the function of smart metering in this process, or they map out the energy behaviour. These studies are of course quite diverse in nature and focus on both organisational and residential contexts[15],[16],[17],[18],[19]. In Flanders, institutions such as VEA (Flemish Energy Agency) and VREG (Flemish Regulator for the Electricity and Gas Market) frequently monitor the energy market by means of customer surveys.

Most of the aforementioned studies make use of the survey methodology. Nevertheless, the way in which these surveys are being conducted differs greatly. Most of them are limited to a study of mere descriptive items, including variables such as household details, possession of different domestic appliances, building types, electricity consumption, and so on.

Another problem with most of these studies is the fact that they are not based on theoretical assumptions or valid measurement batteries. The questions are institution-specific and pragmatic. And here again the use of one-intention based questions for assessing user adoption or user acceptance (e.g. to what extent would you make use of this or that technology?) inevitably leads to false realities [20].

Methodology

In our research, a quantitative survey was held throughout Flanders in 2010. The population of the research consists of 1326 households in Flanders that are equipped with Synthetic Load Profile meters (SLP[1]). The reason why this population is chosen lies with further research goals within the project in which this user research is embodied. The SLP-meters will allow to investigate the actual energy use of the population. A sample of 500 household was taken from this population, taking into account different types of households such as young singles, families with young children, families with grown-up children and retired people. In general, the questionnaire contains questions about several topics such as housing parameters, mobility, insulation measures, heating, lighting, energy patterns, domestic appliances, ICT and multimedia, ecological behavior, ecological attitude, socio-demographic parameters like gender, age, profession or income and most important: about impressions of smart appliances.

The data was collected from the beginning of March 2010 until the end of May 2010. Computer Assisted Personal interviews (CAPI) were held within the SLP-households.

Impression of smart appliances

Our main interest is the impression that Flemish households have of smart appliances. To measure this impression, we will use the Technology Acceptance model (TAM). The model was developed by Davis [21] and is rooted in the theory of Reasoned Action (TRA). The model was designed to make an assessment of the determinants of technology acceptation prior to the launch of the innovation, when users have no experience with the innovation yet. The four main constructs of the model are Perceived Usefulness (PU), Perceived Ease of Use (PEoU), Attitude toward using and Behavioural Intention to use (BI). PEoU refers to the degree in which a potential user expects that a new technology will be easy and not too complex to use. PU refers to the degree in which the potential user expects that the new technology will be useful and will deliver advantages compared to the present way of working. The baseline of the model is that Perceived Ease of Use and Perceived Usefulness can be used to predict the intention to use. Though TAM is mostly used for information technology, we believe that the ideas that are behind the model are definitely also applicable in the context of innovative technologies with regard to energy efficiency.
The hypotheses of the Technology Acceptance Model can be stated as follows:

- H1 PEoU has a significant positive influence on PU
- H2 PU has a significant positive influence on Attitude towards using
- H3 PEoU has a significant positive influence on Attitude towards using
- H4 PU has a significant positive influence on BI
- H5 Attitude towards using has a significant positive influence on BI

[1] Synthetic Load Profiles are used to estimate the energy consumption at a certain acces point per billing period

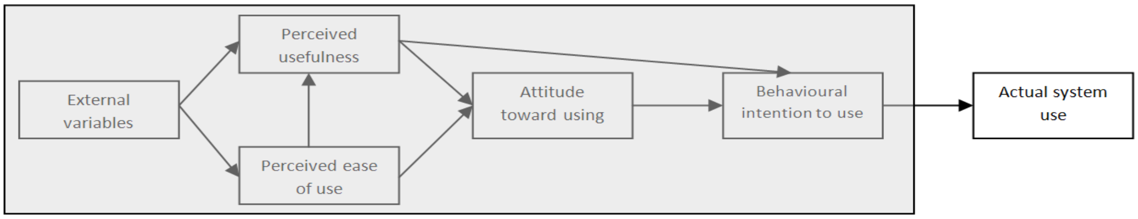

Figure 1 - The Technology Acceptance Model

In our research we will not be able to measure the actual system use, since smart appliances do not yet exist in the households. Therefore, we will use a reduced TAM-model, with an exclusion of the actual behaviour. This is not a problem for our research since the basic aim is to get an impression of what the respondent's attitude and intention towards smart appliances is. Key in this context is that we provide them with a clear description of what smart appliances are (see appendix), what they can do and what the implications of using them will be.

In addition to the TAM items, a number of extra variables were added in the questionnaire. These variables concern topics like safety, comfort and control. These items will not be included within final model. We will discuss their values in later section of this paper

Instrument development

The final questionnaire contained two parts with regard to perception of smart appliances. The first part were the items of the Technology Acceptance Model, the second part contained exploratory items with regard to smart appliance issues like safety, control and comfort.
The interviewer provided the respondents with a introductory description of what smart appliances are and what they can do (see appendix). This part is very important because a poor knowledge about smart appliances makes the whole measurement useless. That is why the interviewers were properly briefed on smart appliances. They were not allowed to continue the inquiry of the respondents if they noticed any unclearness about it.
All constructs in the Technology Acceptance Model are measured with items adapted from earlier research. A Likert-scale ranging from 1 (completely disagree) to 5 (completely agree) was used. Table 1 (see appendix) presents an overview of the items used in the model.

Table 2 (see appendix) presents the items used to measure safety, control and comfort. All of the items were measured on a 5-point Likert-scale ranging from 1 (completely disagree) to 5 (completely agree). The scores for safety, control and comfort were reversed to correct the negative formulation of their items.

4. RESULTS

Overall perception of smart appliances

Taking the four constructs used in the Technology Acceptance Model and adding the three extra exploratory constructs safety, comfort and control we obtain insights in the perception of our respondents on 7 dimensions regarding smart household appliances. Table 3 shows the mean scores and of the respondents for each of these dimensions, ranging from a minimum of 1 to a maximum of 5. A high score on a constructs indicates a positive evaluation, a low score indicates a negative evaluation.

Table 3 – Mean scores

	Mean	SD
Perceived Usefulness	3,1	1,0
Perceived Ease of Use	3,3	0,9
Attitude	3,5	0,9
Intention to Use	3,6	1,1
Safety	2,9	1,1
Control	2,9	1,2
Comfort	3,9	1,0

Figure 2 presents the distribution of the mean scores of the sample on the 7 dimensions. It shows that our respondents do not have the impression that using smart appliances will cause a loss of comfort. For control and safety on the other hand, the mean scores are quite lower, which signifies a rather lower degree of trust in the appliances. Though a mean score of 2.9 for safety and control is still a rather neutral score, these issues should to be taken into account in the future. The attitude and intention to use smart appliances have a medium score which signifies that on average our respondents are not negatively oriented towards smart appliances. Usefulness and ease of use have a somewhat neutral score. Overall, we see a moderately positive attitude towards smart appliances. There are no extremely negative scores on the constructs, but also no extremely positive scores.

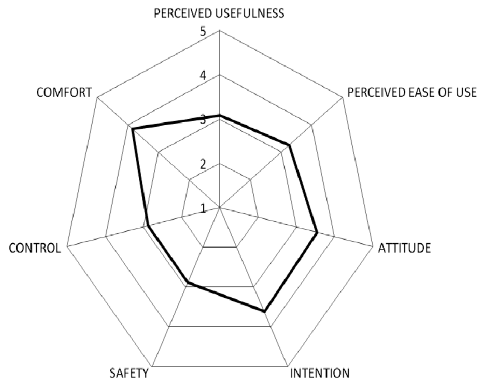

Figure 2 – Mean scores

TAM: Model fit

We tested the model fit using multiple fit indices: Normed Fit Index (NFI), Relative Fit Index (RFI), Incremental Fit Index (IFI), Tucker-Lewis Index (TLI), Comparative Fit Index (CFI) and Root Mean Square Error of Approximation (RMSEA). Table 4 gives an overview of these fit indices with their recommended value and the value that was obtained in this study.

Table 4 – Overall fit indices

	Value
Normed Fit Index (NFI) (≥ .90)	0.932
Relative Fit Index (RFI) (≥ .90)	0.916
Incremental Fit index (IFI) (≥ .90)	0.946
Tucker-Lewis Index (TLI) (≥.90)	0.933
Comparative Fit Index (CFI) (≥ .90)	0.946
Root Mean Square Error of Approximation (RMSEA) (≥ 0.08)	0.084

As shown in table 4 all fit indices except for RMSEA meet their requirements. Though its value is higher than it is theoretically allowed, RMSEA still approaches closely its recommended value and we can therefore accept it. Chi-square, which is commonly used as a goodness-of-fit parameter, was not used here because of its sensitivity to large sample size. Given our 500 respondents, we decided not to use Chi-square as a fit index. As a conclusion, we can state that our data fit the structural model reasonably well.

All constructs of the Technology Acceptance Model were measured using three to four items. Table 5 gives an overview of the mean values obtained for each of the items, their respective Standard Deviations and the construct's Cronbach's α.

All Cronbach's α's, except for Attitude meet the recommended value of 0.70. The α for attitude is 0.69 but we can accept this as it is really close to its recommended value.

Table 5 – Item results

	Mean	SD	Cronbach's α
Perceived usefulness			
PU1 (tam3)	3,0	1,3	0,86
PU2 (tam5)	2,6	1,2	
PU3 (tam12)	3,2	1,3	
PU4 (tam9)	3,5	1,2	
Perceived ease of use			
PEOU1 (tam2)	3,3	1,1	0,83
PEOU2 (tam4)	3,3	1,2	
PEOU3 (tam7)	3,2	1,1	
PEOU4 (tam10)	3,3	1,2	
Attitude			
ATT1 (tam1)	3,3	1,3	0,69
ATT2 (tam14)	3,8	1,1	
ATT3 (tam11)	3,5	1,1	
Intention to use			
INT1 (tam15)	3,7	1,2	0,93
INT2 (tam8)	3,8	1,2	
INT3 (tam13)	3,5	1,3	
INT4 (tam6)	3,5	1,3	

Overall model and hypotheses

The testing of the model was done using AMOS 5. Figure 2 presents the results of this testing. Supporting hypothesis 1 of the Technology Acceptance Model, Perceived Ease of use has a significant positive influence on Perceived Usefulness (β=0.81, $p < 0.001$).

Perceived Usefulness has a significant positive influence on Attitude towards using (β=0.84, $p < 0.001$), which supports hypothesis 2. Hypothesis 3, Perceived Ease of use has a positive influence on Attitude towards using, was supported by the data (β=0.15, $p < 0.05$). PU has a significant positive influence on BI (H4) was not supported as well (β=0.29, ns). Hypothesis 5, Attitude towards using has a significant positive influence on BI, was supported by our data (β=0.65, $p < 0.05$).

The explanatory power for the model can be measured through the R² values for the dependent constructs. Perceived usefulness and Perceived Ease of Use account for 93% of the variances observed in the respondents Attitude towards smart appliances. Perceived Usefulness and Attitude account for 88% of the variances in the respondents Intention to use.

Discussion

The results show us the applicability of the Technology Acceptance model for measuring the perception, attitude and intention to use smart household appliances. Perceived Ease of Use was found to have a strong influence on Perceived Usefulness. This implies that people will consider smart appliances more as useful, if operating them is not a hard thing to do. This means that manufacturers will have to take the ease of use into account. Both Perceived Ease of Use and Perceived Usefulness have a significant influence on Attitude. The path coefficients indicate that Perceived Usefulness has the strongest effect, which means people need a thorough perception of how useful smart appliances can be to them in order to have a positive attitude about them. The same conclusion can be drawn for Perceived Ease of Use. If the perception of smart appliance usage is that they are easy to use, or at least not more difficult to use than regular household appliances, this will contribute to a positive attitude. No significant effect of Perceived Usefulness was found on Intention to use. Poor knowledge about the usefulness of smart appliances in terms of energy efficiency and financial profits for households, but also in terms of environmental impact and energy production efficiency could explain this insignificant effect. Attitude on the other hand, does have a positive effect on intention to use with regard to attitude formation about this new generation of energy efficient household appliances. Attitude then, has a significant positive effect on the intention to use smart appliances, which implies that a positive attitude will result in a greater intention to use.

In further analyses it will be investigated to what extend constructs like safety, control and comfort have an impact on attitude formation and behavioral intention to use through Perceived Usefulness and Perceived Ease of use. A next step that will be taken is the segmentation of our samples into groups with different attitudes and perceptions towards smart appliances.

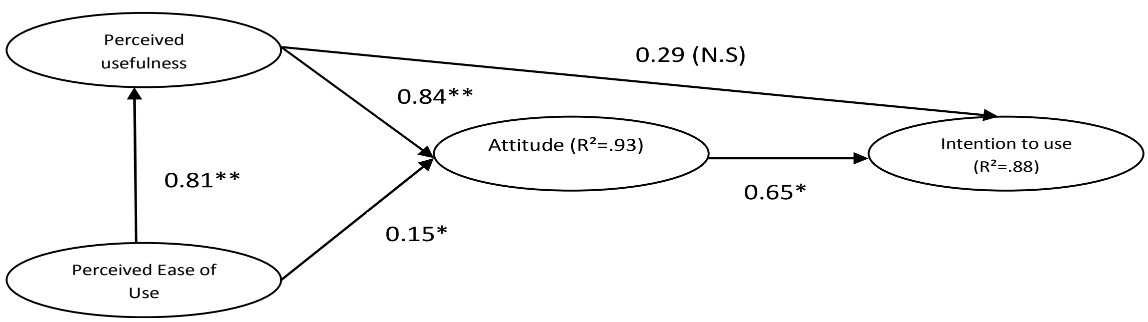

Fig 3 – Final model

5. CONCLUSIONS

In this paper the first results of a quantitative survey in Flanders (N=500 households) are presented. The goal was to gain insights in households' perception of smart appliances. The Technology Acceptance Model was used a theoretical framework to manage this.

First an overall impression of smart appliances was given by mapping the results of the households on the TAM constructs and the three additional exploratory constructs (safety, control and comfort). This made clear that a challenge may lie in convincing people about the safety of demand side management (and the use of smart appliances) and the control that they would still hold over their household appliances.

Second, the TAM constructs were used in the Technology Acceptance Model path diagram. Results show that Perceived Ease of use and especially Perceived Usefulness are important

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APPENDIX

Introductory description of smart appliances provided by the interviewer (translation)
Smart appliances can be situated in the modernization of the energy use of households into an energy efficient network or Smart Grid. Smart appliances are e.g. washing machines, dishwashers, refrigerators, … that can regulate their own energy use. They can e.g. decide when certain energy consuming tasks will be carried out. Possible applications are that a washing machine starts operating when its receives a signal that renewable energy is available or when night tariff for electricity is available. Another possibility is that, when starting up the appliance, the user receives the message that it would be more cost efficient and environmentally friendly to postpone its task to a later time during the day or night. The user stays in control of whether or not the appliance will operate. Another possibility is that the appliance interrupts its own electricity consumption for a short period. A refrigerator e.g., can keep its temperature for quite some time, even when shut down, without any consequences for the food.
To conclude, it can be stated that smart appliances can help the consumer to make efficient and informed choices with regard to their energy consumption. The incremental cost of the appliances remains limited when produced on a large scale. There will be a small extra cost for the data communication, but the rise of broadband networks will keep reducing this cost in the future. The recovery time for this investment will depend on the way the end-user will be compensated. It is to be expected that it will be remarkably shorter than the life span of the appliance.

Table 1 – Items used in the model (translation)

	Items
Perceived Usefulness	-Using smart appliances would allow me to live more energy efficient
	-Using smart appliances would increase my productivity
	-Using smart appliances would make me work more efficiently
	-I believe smart appliances are useful for me
Perceived Ease of Use	-Learning to work with smart appliances seems easy and clear for me to understand
	-Working with smart appliances would not demand a lot of thinking
	-Smart appliances are easy to work with
	-It is easy to make a smart appliance do what I want
Attitude	-Using smart appliances is a good idea
	-Using smart appliances has a lot of advantages
	-Using smart appliances seems to have no positive contribution to me *(reversed)*
Behavioural Intention to Use	-If I had a smart appliance at my disposal, I would use it
	-If I had access to a smart appliance, I predict that I would use it
	-I would use smart appliances in every way that is possible
	-If I get the opportunity, I will use smart appliances

Table 2 - Items used for safety, comfort and control

	Items
Safety	-I am not sure about the safety of these smart appliances (e.g. fire, food quality) *(reversed)*
	-I think I would let smart appliances operate when I'm not at home or asleep *(reversed)*
Comfort	-I think using smart appliances would disrupt my rhythm of life *(reversed)*
	-I think using smart appliances will cause me a loss of comfort *(reversed)*
Control	-In my opinion, smart appliances do not allow a lot of control of the user *(reversed)*