Computing Systems for Household Energy Conservation: Consumer Response and Social Ecological Considerations

L. T. McCalley, C. J. H. Midden & K. Haagdorens
Human-Technology Interaction
Technical University Eindhoven
P.O. Box 513
5600 MB Eindhoven
+31 (0)40 247 4581
l.t.mccalley@tm.tue.nl

ABSTRACT
In this paper, we describe our position regarding the importance of social cognitive factors in developing human-computer dialogues to support household energy conservation. A description of empirical research results is presented in support of the importance of social, personality and cognitive variables involved in presenting information to users that supports human motivation to conform to society's needs for saving energy.

Keywords
Human-computer interaction, goal setting, feedback, energy conservation, social cognition

INTRODUCTION
The position of the authors is that more attention needs to be focused on the everyday household use of computers if their ecologic impact, in terms of energy efficiency and conservation, is to be controlled and directed in a positive way. In addition, social, psychological and personality variables must be understood in order to design systems that are successful in implementing and supporting conservation behavior.

In the discussion of computers and ecology many individuals envision concerns regarding computer hardware, whether it be regarding recycling or the increasing purchases of home computers and related equipment that consume ever more energy. Others think of the positive impact of increased efficiency of energy resource allocation through computer control. These are valid concerns that warrant address however it is most likely that action will come through policy changes that require manufacturers to improve products for recycling, to improve energy efficiency of computer products, and for energy providers to maintain better control of energy distribution networks. In other words, these are primarily macro-level problems, likely to be tackled by government. However, no matter how energy efficient computer equipment becomes, or how recyclable, or how well energy related resources are distributed, human behavior will still have a large impact [29].

Changing lifestyles create an energy demand that is not in keeping with global demands to lower energy consumption and CO_2 emissions and to insure a sustainable energy supply [10]. Although the past decade has seen a significant improvement in the advancement of energy efficiency in the household, where it is estimated that the use of the best currently available technology could reduce present energy consumption by 30% [10], it would be a mistake to neglect interventions that target consumer behavior. In fact, it may prove vital to counter changes in user behaviour that are brought about by technological interventions due to the "rebound effect" [26,27]. This means that on a micro-level, money saved by technological interventions is often spent on other energy-consuming activities; similarly, technology may change the way products are used. For example, a new, energy-efficient car may make it more difficult for people to resist using it for short distances rather walking; likewise, economic water boilers may cause people to take longer showers. On a macro-level, a surplus of energy causes a reduction in cost price to the consumer, which in turn undermines motivation to reduce household energy use. [25]. Despite the difficulty in making estimates due to cascade effects some researchers claim that user behavior is responsible for the waste of large amounts of home energy use. In 1978 Sonderegger [24] reported that in the United States, 33 % of home energy use is attributable to user behavior and for the Netherlands Verhallen and Van Raaij [28] reported 26 % in 1980. More recent estimates are scarce, but some researchers suggest that households could save in the range of 10% or more on gas for space heating alone [7, 30], and 15% of electricity used for cooking [29].

Thus, changes in consumer behavior can offer a substantial contribution to the energy saving capacities of modern technology. We suggest that the best means to do this presently is through carefully designed interfacing between computer controlled individual appliances, centralized systems such as domotic (computerized household control) or “smart home” systems and home personal computer programs. When computers become ubiquious in the home setting, where they might even become part of our clothing, motivation opportunities will expand. Nonetheless, it is the interactivity of the system that provides the advantage over other means of motivating and influencing humans [11]and the fundamentals of how computers can, and will be able to, motivate conservation behavior can be best studied now, using realtively common appliances and interfaces. Our own research in this domain began with product-integrated feedback where appliance interfaces are capable of giving users constantly updated feedback information as to the amount of energy they are using as well as allowing them to set an energy conservation goal [17, 18].

MOTIVATION AND THE USER

Past studies have shown with some certainty that aggregated energy use feedback often has little effect on the motivation to conserve energy unless it is given over the short term and in combination with some other encouragement to conserve energy, whether to spur competition [30], set a goal [5], or attain a commitment from the consumer [23]. The first study in our laboratory investigated product-integrated energy feedback. The study used a computer simulation of a washing machine control panel and confirmed that even instantaneous feedback specific to one appliance is not effective if no conservation goal has been set. Further simulation studies led to the conclusion that product-integrated energy feedback, when coupled with a conservation goal, is a highly successful means of motivate energy consumption behavior. Furthermore, other concurrent interventions, such as those meant to change attitudes towards conservation, can activate goals other than saving energy and cause the user to abandon the conservation goal [19].

These studies also took into consideration the social orientation of the user and found that pro-social individuals performed better using an assigned goal and pro-self individuals conserved more energy when allowed to set their own goals. The last study in this series was a field study where actual washing machine control panels were designed and built with better computing capacity than current microprocessor run machines and placed in people’s homes for household use. The experimental panel allowed subjects to see how much energy they normally used to wash, set a conservation goal, receive feedback for every washing program chosen and continually monitor energy use and goal achievement. The field experiment confirmed positive laboratory results and consumer enthusiasm for having control over their energy use.

SYSTEM DESIGN AND USER CONTROL

When it is considered that costs to similarly upgrade other electronically controlled appliances, especially those that consume larger amounts of energy, would be minimal, it can be concluded that results would be highly desirable. Using existing smart home technology, all household appliances could easily be monitored for energy use in the near future. Furthermore, this information could be displayed via any computer in the household. Energy goals could then be set for either individual appliances or for total household energy use through the computer and users could have maximum control over household energy use. This type of system would allow a more integrated and specific overall picture of household energy consumption. The system would offer much more information, and thus control, than the standard monthly bill (or yearly bill, in the case of the Netherlands) that gives only aggregated energy use feedback. Furthermore it would show users the precise sources of highest consumption, allowing for changes in the household consumption pattern to be made with little effort or cost. Such a system would be considered a domotic system, although current centralized control systems utilize their own control panels and do not give the capability for individual appliance feedback or goal setting.

The expectation in the field has been that a central control system will soon exist that makes adjustments and trade-offs for the residents that will allow them to experience a comfortable home environment with high energy efficiency and with virtually no effort cost to themselves. This means that the domotic system can be set to conserve energy, removing responsibility and control from the homeowner. If this becomes the case then the question of energy feedback would become a moot point. However, that is clearly not going to happen as human beings require some sort of control over their comfort and living environments [22]. The reality is that consumers demand more and more options and controls in their electronic systems [14,20]. This suggests that domotics will emerge as a combination of electronic systems and appliances with more extensive, and individualized, interface options with a central household guidance system under human control. It is thus more important than ever to understand the relationship between goals, feedback and feed forward information and human behavior in the context of energy conservation.

Our own research in this area has utilized studies of programmable thermostats as micro-domotic systems in order to understand these relationships and give insight into how humans behave with larger and more complex domotic systems. As with the washing machine studies, non-novel appliances were chosen as the underlying fundamental processes of human behaviour can only be understood in the context of familiar things.

The programmable thermostat presents a unique opportunity to investigate both feed forward and feedback in combination with goal setting as it has two distinct phases of use, initial programming and daily use. This makes the electronic programmable thermostat a small-scale example for larger domotic systems that will also require programming prior to daily use. The project was the study of the effects of the level of specificity of conservation information and goal setting given to consumers before they program a clock thermostat.

A short survey was conducted prior to the thermostat experiment in order to identify possible social variables related to the interactions of household members that might moderate the effects of conservation efforts. It was discovered that other household members override the program of the thermostat on a daily basis. This finding suggested the potential for household conflict that could be a moderator of setting the thermostat in a manner conducive to energy conservation.

The thermostat experiment itself revealed that subjects who did not own a programmable thermostat and had not previously used one, saved more energy than subjects who were experienced in using such a thermostat. It was speculated that subjects inexperienced in the use of the clock thermostat had the expectation that their conservation efforts, reflected in the program settings, would remain in effect and apparently did not take into account household conflict where other household members might not be as willing to sacrifice comfort for conservation. A second experiment confirmed the assumption that the anticipation of the interference of other household members attenuated conservation behavior in programming the thermostat.

Thus, what we have learned so far is that if we want to design a home computer system to control energy use and encourage conservation, we must allow users to have some freedom of control of the system, give them appropriate feedback, allow them to set a conservation goal, and take into consideration that a household is not always, or even usually, a single person (for even when a person lives alone, others are likely to interfere with such things as the heating temperature; see McCalley, 2003). The control system must be built for all household users or the household member most responsible for program settings is likely to forego conservation efforts. It must also be kept in mind that total control of the system by the user is likely to lower the efficiency of the system and total control by the system itself will cause it to be rejected by the user. It is therefore necessary to find the correct balance of control between the user and the system.

ONGOING RESEARCH

In an attempt to design such a system, we are currently combining what we know to date about household users and develop criteria for a software program that can take into account the important variables that influence household energy conservation. Such a system should be able to provide energy-related feedback that is appropriate, and specific, to *each* household member. Our primary focus is on the goal to save energy. As previously mentioned, having a goal is the crucial motivating factor. It is also known that the goal and the feedback must match, and attention must remain focused, in order for the goal to remain active. Developing appropriate feedback is not difficult, however, encouraging the continuing priority of a specific goal is extremely difficult due to the dynamic nature of goals [2]. We therefore propose that computers can only be efficient in supporting conservation when goal prioritization is understood. It might also be said that any computer program designed to support a particular human behavior, or set of behaviors, can only be fully successful when the related goal hierarchy of the individual user is understood. As has also been illustrated by the thermostat experiment that revealed the effect of anticipated goal conflict on new users, goal conflict resolution between two or more users also needs study.

A new research project has now begun with the long-term purpose of developing a computer program to support household energy conservation using intelligent agents. It is proposed that each household member can receive individual conservation support that is coordinated with the goals of other household members. An example is where one household member gives comfort priority, and another gives priority to financial or conservation goals. An intelligent agent could autonomously give energy-advice to each household member. When an interactive interface is set up where each member can respond to the given support, an agent can accumulate knowledge and set up individual user profiles. In this manner the inferential capability of intelligent agents can be more tailor-made for each member. However, a successful integration of an intelligent agent in a household, depends a lot on the confidence of the family members towards the agent. This confidence level is measured by comparing the given advice (based on a weighted sum of distances between different goals of different people) and the expected advice via a feedback interface. In a later stage when confidence is growing, the user can set 2 confidence thresholds to control an agent's actions: the tell-me threshold and the do-it threshold. An agent will give advice (e.g. shut down decorative lights) if the confidence level for comparable situations is higher than the tell-me threshold. Likewise the agent can autonomously take action (e.g. lowering the thermostat) if the confidence level of the action is over the do-it threshold. This implies that by designing an intelligent agent, a lot of attention must be paid to developing a confidence relationship building interactive interface. Factors that may influence the confidence relationship are for example [1,19]: the design of the user interface, the experience the user has with agents, the way the performance of the agent is predictable, the amount of information the agent provides, shared values between the user and the agent. In the mean time, agents could reduce risk perception for the user by helping them to reduce uncertainty towards a situation or bringing in some alternatives to solve a problem.

However before we can reach the point of designing such an intelligent agent program directed to multiple household users we must first begin with the following research questions:

1. What goals within the household actually relate to energy use?
2. Which parameter best determines the priority of goals related to energy use for the individual?[1]
3. Can goal prioritization be prompted via feedback as suggested by Kluger and DeNisi [15]?
4. What role does goal inhibition play in prioritization and maintaining the user's commitment to a conservation goal?
5. How can conflict resolution be modeled?

In summary, it is our position that the future of household energy conservation lies in the building of successful human-computer interaction that takes into account social and personality variables. To date, the use of a social cognitive framework has been successful in identifying some of the moderating factors of human motivation in energy consumption. However, it remains for future fundamental and applied research to gain a better understanding of other social and cognitive factors that influence family dynamics, goal prioritization and goal conflict before computer applications can be put into effect to further the greater social aim of energy conservation.

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