Environmentally-Friendly Product Development

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(Eds.)

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added value, so it is recommended to weigh up accurately whether the benefit of higher eco-friendliness outweighs the loss of attractiveness and therewith of marketability. Besides this, the eco-friendliness of a product itself is not an option to provide added value to the customer. The added value has to be provided by other product characteristics, e.g. design characteristics.

5.3 Ergonomics in Environmentally Friendly Product Design

5.3.1 Background

This chapter presents the results of an empirical research programme on the ergonomic design of environmentally friendly consumer products. The main goals of the programme were twofold. First, it aimed to develop new methods and to improve existing ones for ergonomic product development. These methods were then evaluated in research studies. Second, it aimed to derive design measures from the analysis of user-product-interaction and to evaluate the effectiveness of these measures in experimental studies with a view to improve the environmental friendliness of consumer products.

User-product interaction is a central aspect of environmentally friendly product development since studies have demonstrated that, on average, about 80 % of the environmental impact caused by energy-driven consumer products occurs during product use, as opposed to preceding and subsequent phases of the product life cycle, such as production or disposal (Wenzel et al. 1997). Against this background, it is not only important to improve the technical efficiency of consumer goods (e.g. reducing energy consumption through a more efficient electric motor) but also to encourage users to employ the appliance in an environmentally friendly manner (Sauer and Rüttinger 2004b; Schmeink et al. 2004).

The design of consumer products poses particular challenges to product developers since the domestic domain differs from a professional work environment in a number of features (Sauer and Rüttinger 2004b):

1. The group of domestic users is characterised by high heterogeneity.
2. There is no selection of domestic users for their competence in operating consumer products.
3. Domestic users do not normally receive any formal training.

4. Domestic users select and define their own tasks.
5. There is usually no performance supervision of domestic users.
6. They usually do not receive any performance feedback from other users.

These differences between application domains have a major implication for the designer. It shows that the possibilities of modifying human behaviour are much more limited in the domestic domain than at work, with system design gaining in importance compared to other measures to achieve behavioural modifications, such as task design, training and selection.

The research reported here is closely related to other work, presented in two other chapters of this book (cf. 3.3, 5.2). First, empirical work on ergonomic design of consumer products for environmentally friendly use needs to pay particular attention to consumer demands since, unlike in work environments, the operator of a technical system is usually its purchaser (Rüttinger et al. 2004). Therefore, it is critical that ergonomic design does not only improve the environmentally-friendliness of products but that these products are sufficiently attractive to consumers so that they are bought in large numbers, at the expense of less environmentally-friendly products. These consumer psychological issues are covered in another chapter of this volume (cf. 5.2). Second, prototypes of environmentally friendly household appliances have been developed (e.g. Weger et al. 2001; cf. 3.3).

5.3.2 Methodological Issues

General Methodological Approach

Advancing product development methods is an important issue since it provides a set of tools for designers to develop and evaluate future consumer products. Therefore, selected methodological questions have been examined in the present research programme.

The studies made use of a range of methods. In order to identify problems of user-product-interaction, studies made use of user interviews, observation and heuristic analyses as primary methods. For the evaluation of the effects of product design features on user behaviour, the main methodological approaches employed were lab-based studies, field studies, computer-based simulation and expert-based methods.

From an ergonomic perspective, one needs to address the question of what design elements are best suited to encourage environmentally-friendly user behaviour. This was achieved by using a four-step approach.

1. An analysis of the user-product-interaction was carried out, using a range of methods, such as observation, interviewing and questionnaires.
2. The data collected allowed us to identify those problems in user-product-interaction that result in environmentally unfriendly user behaviour (e.g. user fills kettle with more water than actually needed).
3. Based on the deficiencies of user-product-interaction that have been identified, measures are derived to improve environmentally friendly product use.
4. The measures derived are tested in an empirical study to evaluate their effectiveness. Based on the results of these tests, recommendations for product designers can be given.

Lab- and Field-Based Simulation of Usage Scenarios

With regard to modelling realistic usage scenarios, the work addressed two pertinent methodological questions. The first methodological question was to determine whether lab-based research is an appropriate methodological approach to gain an understanding of environmentally friendly user behaviour in the domestic domain. Most usage scenarios of the domestic domain can be modelled in a laboratory, which would have obvious benefits to field research in terms of controllability and cost. However, it needs to be evaluated whether research in a lab-based context would not have undue influence on user behaviour, resulting in non-representative user behaviour. Therefore, two field studies were carried out to determine the generalisability of findings previously obtained in lab-based studies (Sauer and Rüttinger 2004a). The two studies investigated the effects of several design modifications (e.g. on-product information, transparency) on environmentally friendly user behaviour during kettle operation. Overall, the findings confirmed the transferability of the results to a field setting.

The second methodological issue was to determine whether static usage scenarios (i.e. user is presented with a paper-based scenario) would represent an appropriate method to collect data about environmentally friendly user behaviour that would be comparable to the findings obtained with dynamic usage scenarios (i.e. lab-based simulation of scenario with real system). Furthermore, if the results obtained with static usage scenarios were indeed very different from those obtained with dynamic usage scenarios, it would be important to identify the nature of these differences. While dynamic usage scenarios are clearly of higher validity, static usage scenarios can be used more efficiently and at lower cost. Two studies were therefore carried out to make a comparative evaluation of different interfaces of a high pressure cleaner, one using static usage scenarios (i.e. coloured photographs of the interface) while the other employed dynamic usage scenarios, that is, operating a fully operational prototype. The results largely confirmed the utility of static usage scenarios for addressing specific research questions. In other cases, it is required to use real operational prototypes (or even computer simulations thereof) because of the great complexity of user-product interaction, which cannot be adequately modelled in static scenarios.

Computer-Based Simulation

Since the employment of realistic usage scenarios with operational prototypes is not always possible, computer-based simulation of complex technical systems is often used as a suitable method (see Brehmer and Dörner 1993). This approach has been used to simulate a wide range of target environments, extending from managerial decision-making (Dörner and Pfeifer 1993) to complex technical work environments (e.g. Lee and Moray 1994). The difficulty of developing a suitable computer-based simulation lies in deciding which aspects of the target system are to be modelled and in what way. To guide the development of such a task environment, a theoretical framework has been developed, describing a general step-by-step approach for design of these simulation tools (Sauer et al. 2000, Sauer et al. 2003a).

This theoretical framework has been applied to central heating systems to identify the needs for environmentally friendly design. This application area is of particular interest since central heating systems are characterised by a high environmental impact and considerable complexity of system operation. For that purpose, a PC-based simulation environment, called CHESS (Central Heating System Simulation) was developed (Schmeink et al. 2003). Fig. 5.13 shows a screenshot of the simulation environment.

The identification of the main features of CHESS was achieved by expert consultation, a heuristic evaluation of current heating systems and a user needs analysis that was carried out in 40 households (Schmeink et al., 2004). An example of such a feature identified is the considerable time lag between user action (e.g. switching on the heating) and system response (e.g., radiator gives off heat). As the next step, task scenarios were developed on that basis, simulating several months of operating the central heating system under various conditions (e.g. changes in outside temperature). A user needs analysis provided indications of the main design deficiencies of current systems.

One of the deficiencies was the poor quality of system feedback, which did not allow users to evaluate their own performance of system operation (e.g. energy consumption). Therefore, the CHESS environment was designed such that different levels of feedback could be modelled.

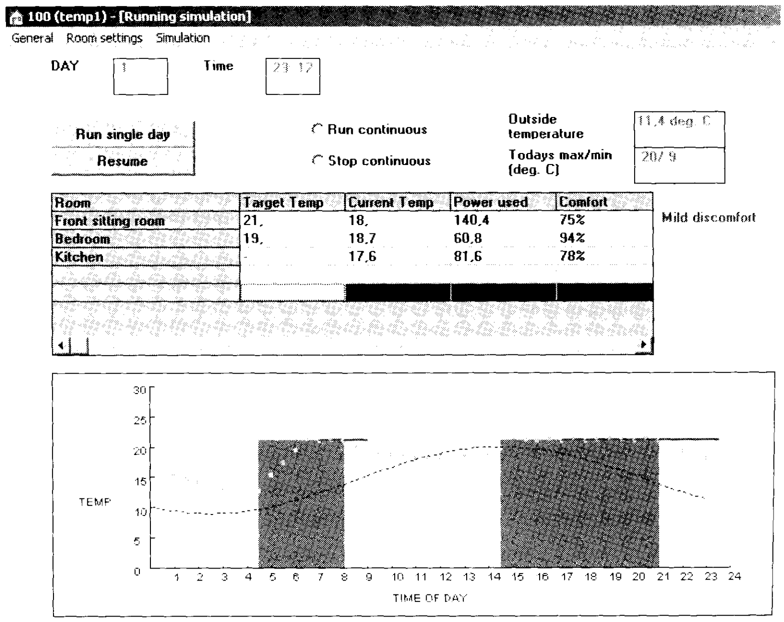

Fig. 5.13. Screenshot of simulation environment CHESS

Expert-Based Methods

A purpose-built method has been developed for the design of environmentally friendly consumer products (Rüttinger and Lasser 2000, Lasser 2002). This method, called Problem Mode and Effects Analysis (PMEA), can be used as a screening tool in early phases of the design process. PMEA has been employed in several research studies to identify different types of user errors (see Lasser 2002; Rüttinger and Lasser 2000). In particular, the modelling of user performance was effective in identifying specific problems in user-product interaction, which were assigned to three categories.

1. *Efficiency problems* refer to a mismatch between user and product (e.g. product is used in an environmentally unfriendly manner).
2. *Functional problems* imply a mismatch between task demands and product functions (e.g. sub-tasks cannot be carried out in an environmentally friendly manner).
3. *Effectiveness problems* involve the setting of inappropriate tasks by the user because of knowledge deficits or motivational problems.

Overall, an evaluation of central aspects of the PMEA method provided promising results, as it proved to be a useful tool for improving product design.

5.3.3 Empirical Research Program

Overview of Research Program

The empirical research program completed comprised 19 major studies with a total number of 704 participants. Table 5.2 provides an overview of the studies being carried out. It shows that six domestic technical systems have been used, covering different complexity levels: vacuum cleaner (nine studies), kettle (four studies), high pressure cleaner (three studies), central heating system (two studies), microwave oven (one study), and washing machine (one study). The report of the empirical findings is divided into three sections. First, we present the results from the analysis of user-product-interaction. Second, we present findings of the evaluation of design-based measures that were derived from the preceding analysis. Third, the influence of user variables on behaviour is reported.

Problems in User-Product Interaction (Analytical Stage)

The first step of the multi-method approach outlined above refers to a thorough analysis of user-product interaction, using a broad range of methods, such as observation, interviewing and questionnaires. In these analyses of user-product interaction, a number of generic problems in user-product interaction have been identified.

An important finding was that habitual behaviour patterns are prevalent in the domestic domain (Sauer et al. 2003b). These tend to be stronger for low-complexity products than for complex systems. It also emerged that the users' actual environmentally friendly performance was usually inferior to their potential environmentally friendly performance (e.g. when users were requested to show their best environmentally friendly performance). This suggests that suboptimal environmentally friendly performance was mainly due to motivational problems and the prevalence of habits while lack of knowledge played a less significant role. It is important to determine the cause of suboptimal environmentally friendly behaviour during the analytical stage since this allows for the best cure to be identified (e.g. breaking habits, increasing motivation, conveying knowledge).

The analysis also revealed the important moderating function of product complexity (Wiese et al. 2004). For example, the inclination of users to read instruction manuals is lower for low-complexity consumer products than for high-complexity products. Similarly, the importance afforded to energy conservation is lower for low-complexity products than for high-complexity products. This indicates the importance of providing product specific recommendations to product developers.

Evaluation of Design Measures (Intervention Stage)

Overall, 23 different design measures have been empirically tested, including automatic adjustment of controls, on-product information, instruction manuals, improved control-display labeling, and enhanced feedback. These design-based measures can be summarised under five headings, representing separate classes of intervention measures:

1. Static user information (on-product information, instruction manual),
2. Dynamic user information (transparency, feedback),
3. Controls design (labeling, position),
4. Automation,
5. Geometric product properties (shape, size).

An overview of the empirical studies with the design-based measures evaluated may be found in Table 5.2.

The summary table shows that most design measures that were evaluated proved to be effective in improving environmentally friendly performance. There were some differences with regard to the effect size of the different measures. It appeared that design measures that do not rely on user motivation alone are particularly effective in modifying environmentally friendly user behaviour. For example, it emerged that the implementation of automatic devices and the modification of geometric properties (e.g. reducing size of appliance also reduces water consumption) were effective even under the prevalence of habits.

Most of the work involved the evaluation of differently designed appliances that were bought off the shelf but there were also studies that involved the development of operational prototypes and its subsequent empirical evaluation (Weger et al. 2001; cf. 3.3).

Influence of User Variables

In addition to design features that are obvious determinants of environmentally friendly behaviour, models of environmentally friendly behaviour suggest a number of user variables that have an impact, such as attitudes and knowledge (Gardner and Stern 1996). In the present research programme, three possible antecedents of environmental behaviour were examined: environmental concern, environmental knowledge and environmental control beliefs.

The findings show that environmental concern has been associated with environmentally friendly behaviour in some but not all studies, typically around a correlation coefficient of 0.3, which is considered a moderate effect size. Interestingly, in two studies using a vacuum cleaner as a model product, high environmental concern was associated with high energy consumption. Although this may appear, at first sight, to be in contradiction to the findings with other household appliances, it may be that users with high environmental concern have a highly positive attitude towards cleanliness, not only with regard to the natural environment (e.g. no littering in the forest) but also in relation to the domestic environment. For environmental knowledge and environmental control beliefs, associations with performance were found to be much less consistent than for environmental concern.

5.3.4 Conclusion

The examination of different methodological approaches confirmed their utility if their application area is carefully chosen on the basis of method-specific strength and weaknesses. The work showed that lab-based simulation methods can provide an effective test-bed for evaluations product development (Sauer and Rüttinger 2004a). Furthermore, the work indicated that static usage scenarios represent a useful method in the context of developing environmentally friendly products. For more complex technical systems like central heating, the utility of computer-based simulation could be demonstrated (Schmeink et al. 2003). In early phases of the product development process, expert-based methods often need to be used, in particular, if a prototype is not yet available. Due to these requirements, PMEA has been developed and evaluated for the development of environmentally friendly consumer products (Rüttinger and Lasser 2000; Lasser 2002).

The empirical research programme was effective in identifying a number of impediments to environmentally friendly behaviour, such as habits, lack of motivation and, to a lesser extent, insufficient knowledge. Furthermore, it demonstrated the effectiveness of a range of design measures to improve environmentally friendly behaviour. Finally, it has to be pointed out that any intervention measure adopted to improve the environmentally friendly performance of the user-product-system does not only have to consider consumer psychological demands. It also requires an estimation of the environmental impact of the intervention measure to ensure that any benefits gained from that measure are not outweighed by increases in the product's environmental impact as a result of the implementation by that very measure.

Table 5.2. Overview of 19 studies on ergonomic design requirements I

Study	Design-based measures SUI	DUI	Ctrl	Auto	Geo	Main findings	Reference
Vacuum cleaner							
Lab-based simulation (N=40)	+		+			▪ On-product information reduced energy use if in spatial proximity to control device ▪ Spatial proximity of controls improved environmentally friendly behaviour ▪ Enhanced display/control label was effective if in close spatial proximity to user	Sauer et al. 2002
Lab-based simulation (N=36)			-	+		▪ Automatic reset of suction controls to energy-efficient level reduced energy usage ▪ No effect of improved control labelling ▪ Impaired ecological performance due to lack of motivation and/or bad habits	Sauer et al. 2004
Lab-based simulation (N=42)	+					▪ Priming users about content of instruction manual (environmental as well as safety prime) increased probability of manual being read	Wiese et al. 2004
Lab-based simulation (N=30)	+					▪ Attaching user information to product was more effective than to packaging ▪ First message of on-product information was remembered better than last message	Wiese et al. 2004
Lab-based simulation (N=36)						▪ Much higher prevalence of habitual errors compared to judgement and knowledge-based errors	Lasser 2002
Lab-based simulation (N=30)		+				▪ Dynamic feedback (indicating unclean floor areas) encouraged users to clean more thoroughly	Unpublished
Lab-based simulation (N=42)				+		▪ Automatic reset of suction control to energy-efficient level reduced energy consumption	Unpublished
Lab-based simulation (N=48)	+	+				▪ On-product information reduced energy consumption ▪ Feedback through dust sensor useful if combined with on-product information ▪ Impaired ecological performance due to lack of motivation and/or bad habits	Unpublished
Kettle							
Lab-based simulation (N=48)	+	-				▪ On-product information reduced water consumption ▪ No effect of improved kettle transparency was found ▪ Impaired ecological performance due to lack of motivation and/or bad habits	Sauer et al. 2003b

Table 5.2. Overview of 19 studies on ergonomic design requirements II

Study	Design-based measures: SUI	DUI	Ctrl	Auto	Geo	Main findings	Reference
Lab-based simulation (N= 48)					+/-	▪ Smaller kettles encouraged users to use less water but shape of kettle had no effect ▪ No effect of time pressure on water usage (i.e. presence of habitual user behaviour)	Sauer and Rüttinger 2004a
Field-based simulation (N=24)	-	+				▪ User support (scale markings and transparency) reduced water consumption ▪ No effect of on-product information	Sauer and Rüttinger 2004a
Field-based simulation (N=18)					+	▪ Smaller kettle encouraged users to use less water	Sauer and Rüttinger 2004a
High pressure cleaner							
In-depth interviews (N=9)						▪ Users often chose inappropriate power settings leading to energy wastage	Unpublished
Static simulation (N=30)			+			▪ Enhanced display/control label improved ecological behaviour ▪ Chosen power settings varied as a function of cleaning scenario	Unpublished
Field-based simulation (N=30)			+			▪ Enhanced display/control label influenced ecological behaviour	Unpublished
Microwave oven							
Lab-based simulation (N=48)	+		+			▪ On-product information reduces energy consumption if control label is enhanced ▪ No improved compliance with information label if additional explanations were given	Unpublished
Washing machine							
Static simulation (N=60)	+		+			▪ Better environmentally friendly behaviour with complex than simple control panel ▪ On-product information improved environmentally friendly behaviour	Unpublished
Central heating system							
Interviews and heuristic analysis (N=40)						▪ Users reported usability problems due to poor interfaces ▪ No feedback about energy conservation strategies	Unpublished
Computer-based simulation (N=45)		+				▪ Improved feedback reduced energy consumption ▪ Aggregated feedback was preferred to detail-oriented feedback	Schmeink et al. 2003

Effect of intervention was found (+) / not found (-); SUI Static user information; DUI dynamic user information; Ctrl Controls; Auto Automation; Geo Geometrics.