# Designed to support or impede energy conservation? How design characteristics influence people's energy use


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**Abstract:** This paper explores how the design of domestic appliances influences people's energy use during everyday activities. Drawing on findings from an interview study with 81 informants, a variety of design characteristics were uncovered, which set preconditions for use that in different ways impede or support energy conservation. The identified characteristics concerned not only appliances' operative functions but also their interactive and communicative functions as well as people's underlying motives for using specific appliances. Addressing the full range of characteristics during the development of new appliances will highlight a variety of design opportunities and increase the possibilities for developing appliances that support people to go about their everyday activities in less energy-reliant ways.

**Keywords:** sustainability; energy conservation; energy use; domestic electricity consumption; product design; design characteristics; appliances; design for sustainable behaviour; DfSB.

**Reference** to this paper should be made as follows: Selvefors, A., Knutsson, J., Marx, C. and Rahe, U. (2017) 'Designed to support or impede energy conservation? How design characteristics influence people's energy use', *J. Design Research*, Vol. 15, No. 1, pp.43–61.

**Biographical notes:** Anneli Selvefors is pursuing a PhD degree at Chalmers University of Technology on the topic of Design for Sustainability. She is interested in the interplay between people and technology and explores this topic in relation to sustainability challenges. Her main research concerns how the design of artefacts influences people's energy use and how everyday activities can be mediated in less energy-intensive ways. She holds a Licentiate of Engineering degree in Human-Technology-Design as well as a Master of Science degree in Industrial Design Engineering from Chalmers University of Technology.

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Christian Marx is a Researcher at Chalmers' Department for Civil and Environmental Engineering. He studied Mechanical Engineering (Dipl-Ing) and Biosystems Engineering (BSc) at the Leibniz University of Hannover/Germany and combined both disciplines in his PhD studies including laser and sensor technologies. Since 2015, he is responsible for the home energy management project (EIT, Climate-KIC, Building Technologies Accelerator) and his interests are in sensor technologies and behaviour recognition for different kinds of socio-technical setups.

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## 1 Introduction

Design for Sustainable Behaviour (DfSB) has emerged as an important field of research that explores the role of artefacts and design in addressing sustainability related challenges (Bhamra and Lilley, 2015; Boks et al., 2015). In recent years, a growing number of research studies in this field have explored what opportunities product design may entail for energy conservation. In contrast to traditional energy conservation research, studying the influence of factors such as attitudes, knowledge and norms on people's energy use (for an overview of different models and factors see Chatterton, 2011), many researchers now argue the importance of exploring the particular influence of appliances on people's everyday energy use. So far, studies evaluating what potential different types of feedback systems have for encouraging energy conservation have been plentiful (see, for instance, Selvefors et al., 2013; Strengers, 2011; Van Dam et al., 2012; Wilson et al., 2016). These studies highlight that feedback systems can increase awareness and encourage energy conservation activities, yet suggest that feedback systems are often unable to change people's preconditions for using less energy in everyday life. Hence, it is also highly relevant to explore how the design of appliances used in the everyday influences people's energy use. As Elias et al. (2009) highlight, there is great potential for reducing energy use associated with the use of many common appliances by improving aspects intrinsic to the appliances as well as people's use of the appliances.

Studies that have analysed the design of specific appliances from an energy conservation perspective have identified aspects that often lead to unnecessary energy use. For instance, after studying people's use of television sets, Rodriguez and Boks (2005) argue that certain functions can cause unnecessary energy use as they are not adapted to the users' needs and that TVs commonly lack many functions that would enable less energy-intensive use, such as appropriate power modes and feedback on energy use. Similarly, studies on people's energy use related to, for instance, cold appliances (Selvefors et al., 2012; Tang and Bhamra, 2012), vacuum cleaners (Sauer et al., 2002), washing machines (McCalley et al., 2011), and electric water kettles (Sauer and Rüttinger, 2004) have discussed similar aspects. Moreover, a few studies have taken a more holistic approach and discussed aspects in regards to various types of appliances. After exploring people's interactions with different appliances, Zandanel (2011) point out the lack of a common communicative approach, and argues that poor communication makes people confused about how much energy their specific appliance use and what they can do to influence it. She also brings forth several issues that limit people's understanding of available functions and how they can be used, such as unclear program settings, complex interface structures, as well as a lack of feedback on usage and status. While Zandanel (2011) primarily discusses aspects related to how people understand an appliance and its functions, Thornander et al. (2011) reveal other aspects based in part on a survey exploring people's understanding of energy-reliant products and in part on a case study of a coffee machine. Their survey suggests that energy wastage could be attributed not only to people's understanding of the product and its energy use, but also to people's use of it partly as a consequence of the technical function and design of the interface. In addition, their case study highlights that energy wastage can sometimes also be attributed to the choice of technology and its efficiency and effectiveness during use.

Even though these studies bring forth important aspects that point to the value of exploring how design influence people's energy use, they are characterised by different limitations. Some studies discuss design characteristics on a very detailed level in regards to particular types of appliances. While they can provide appliance specific recommendations, they are often less relevant for aiding design of appliances in general. In contrast, the studies that do highlight more generic aspects commonly provide a limited set of characteristics, often on different level of generality, and thus fail to systematise them in a way that cover, and highlight, the full scope of characteristics and design possibilities. Gaining a more holistic understanding of the variety of artefact related aspects influencing why people may not be willing, or able, to use less energy, is essential in order to identify new ways of supporting energy conservation from a design perspective. The aim of this paper is therefore to explore the multitude of design related aspects that set preconditions for people's use of appliances and energy in order to identify relevant design characteristics and discuss opportunities and implications for design.

Findings from an interview study with 81 informants are used as a basis for exploring different aspects perceived to support or impede energy conservation in relation to different types of appliances. The paper initially introduces the study and the findings, and subsequently discusses the contribution and what implications the findings have for the design of domestic appliances from an energy conservation perspective.

## 2 Method

The findings presented in this paper draw on the results from an interview study exploring people's use of domestic appliances. This paper will specifically present the study's result regarding what preconditions the design of domestic appliances set and how they influence people's energy use.

### *2.1 Data collection*

The recruitment of informants was carried out through distributing invitations via housing associations, a local newspaper, social media, and personal networks. Only single households were recruited, as this specific focus was relevant for the overall study. In total, 81 persons in the greater area of Gothenburg, Sweden, volunteered to participate. The group of informants consisted of 59% women and 41% men and ages ranged from 19 to 93 years with a majority of informants between 19 and 29 years (37%). The informants' self-rated awareness of their energy use varied from not at all aware to very aware and 61% of the informants considering themselves to be somewhat aware. All informants lived in apartments; the majority had an apartment with one room and a kitchen (41%) while others had two (30%), three (20%), four (7%) or five rooms and a kitchen (1%).

A team of researchers and master's students conducted the data collection by carrying out semi-structured interviews in the homes of the informants with the help of a digital interview guide accessed through a tablet and a customised web application. The interview guide was pilot tested and adjusted to better support a fruitful dialog between informant and interviewer. Interview notes as well as photographs taken by the interviewer, were directly documented via the web application and stored in an online database. The team performing the interviews was initially briefed about the study, informed about the interview guide, and given instructions on how to use the tablet interface to ensure comparable procedures for all interviews.

## *2.2 Data analysis*

The analysis of data included two parts. First, the informants' answers to the specific interview question: "Which of your appliances do you consider to be particularly difficult to use in a less energy-intensive way?" were analysed. The informants had been encouraged to highlight two examples and provide specific reasons, whereupon they were asked to elaborate on their use of the appliances during everyday activities. Based on this data, an inventory was compiled to provide an overview of the types of appliances the informants had mentioned. Moreover, the reasons why particular types of appliances were difficult to use in a less energy-intensive way were examined in order to explore if any similarities could be found between different types of appliances.

Second, to get a holistic overview of different design characteristics that influenced the informants' energy use, explicit descriptions of aspects and narratives related to the informants' experiences of interacting with appliances were analysed. A procedure for analysing interview data described by Miles and Huberman (1994) was followed in which data segments were clustered into themes and subsequently grouped in subthemes. A categorisation of artefact-related aspects proposed by Selvefors et al. (2016) was used as a basis for organising the identified design characteristics according to five hierarchically ordered layers: *communicative functions, interactive functions, operative functions, artefact type(s)*, and the overall layer *enabled activity.* This particular categorisation was used as it hierarchically arranges artefact-related aspects into different layers of design that influence people's preconditions for interacting with technology in different ways. The categorisation thus provides a suitable basis for organising the identified design characteristics and for discussing what preconditions they may entail for people's use of appliances and energy from a design perspective. The categorisation's nethermost layer, an artefact's communicative functions, set preconditions for users' perception of the artefact. This includes for instance the perception of the interaction, such as understanding its purpose and how to use it, as well as the perception of the artefact itself and its properties. The next layer concerns an artefact's interactive functions that determine people's possibilities for accessing and making use of the operative functions. The design of the interactive functions sets the preconditions for how easy it is to use the artefact and thus influence whether or not the user can control and interact with the artefact in a less resource-intensive way. The third layer concerns an artefact's operative functions and is divided into two sublayers, *practical functions* and *operating concept*, which both set preconditions for use and for the resulting resource use. The operating concept deals with which technical approach is taken to provide an artefact's main function while an artefact's practical functions more directly set the preconditions for use and determine what the user should be able to do with the artefact. The layer that concern artefact type(s), addresses what type of artefact it is and if this type of artefact can enable people to fulfil their needs in a way that suit them and their requirements. Finally, the overarching layer concerns what activity an artefact enables and what motives and needs it supports.

## 3 Appliances considered difficult to use in a less energy-intensive way

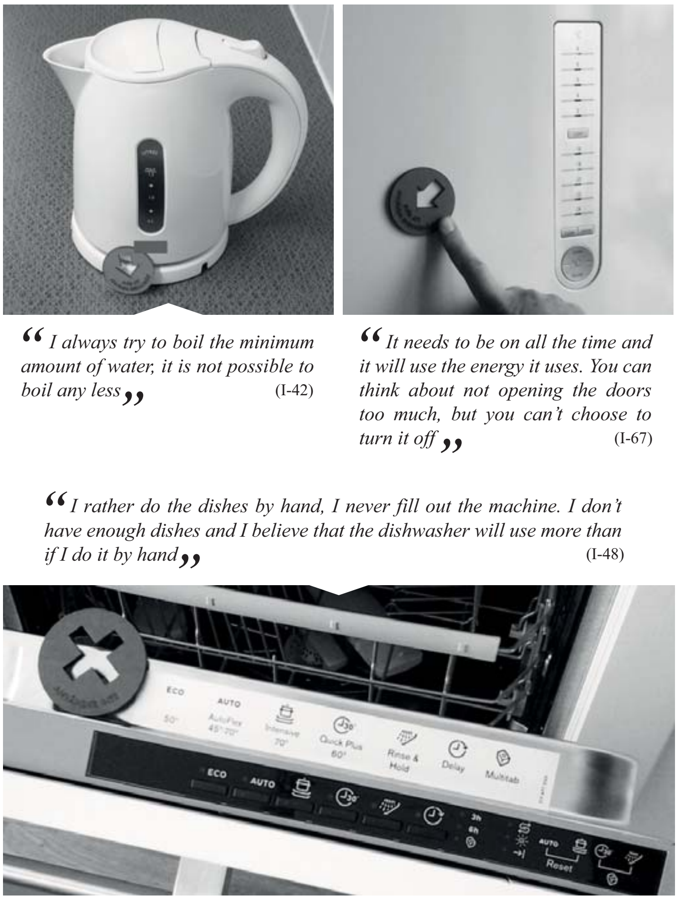
When asked to point out two particular products they considered difficult to use in a less energy-intensive way, the majority of informants (I-s) found it easy to come up with specific examples. Two informants, however, struggled and could not pinpoint any concrete examples even though they had touched upon the topic during other parts of the interview. In total, the informants pinpointed around forty different types of appliances, spanning from white goods to lighting and smaller electronic devices, see Table 1. As the majority of informants possess the most commonly mentioned types of appliances, and as they are most often frequently used, it may not be unexpected that many gave them as examples. The variety of mentioned appliances does, however, suggest that it is not only the main and most frequently used household appliances that are perceived as difficult; other appliances used to a lesser extent were also highlighted, such as toasters, printers, and vacuum cleaners.

**Table 1** Overview of appliances the informants described as difficult to use in a less energy-intensive way

| | Type of appliances (total number of times mentioned by the 81 informants)<br>*Specifically mentioned appliances* |
|---|---|
| Major appliances | Food preparation appliances (31)<br>*Stoves, cooktops, oven, microwave ovens, and kitchen fans* |
| | Food preservation appliances (24)<br>*Refrigerators and freezers* |
| | Washing equipment (10)<br>*Dishwashers and washing machines* |
| Small appliances | Kitchen appliances (10)<br>*Coffeemakers, electric hand mixers, electric water kettles, sandwich makers, waffle irons, and toasters* |
| | Lighting (4)<br>*Ceiling lamps, desk lamps, and other small lamps* |
| | Other household appliances (13)<br>*Irons, sewing machines, towel dryers, hair driers, air purifiers, electric heaters, electric floor heating, and vacuum cleaners* |
| Consumer electronics | Entertainment and communication equipment (24)<br>*Television sets, radio and stereo equipment, mobile telephones, and GPS watches* |
| | Office equipment (13)<br>*Laptop and desktop computers, printers, and broadband devices* |

Moreover, even appliances that offered specific functions and support for reducing energy use were mentioned to be difficult to use in a less energy-intensive way, see Figure 1. For instance, many informants used electric water kettles because they enabled energy efficient boiling even though the design often forced them to boil more water than needed. One informant considered it difficult to reduce the energy use of her combined refrigerator and freezer even though it offered possibilities for adjusting temperature settings. Another informant had a dishwasher offering an eco-mode but the dishwasher was never used as he considered it too big for his needs.

**Figure 1** Examples of appliances considered difficult to use in a less energy-intensive way even though they offered specific functions and support for reducing electricity use, (a) electric water kettle (b) combined refrigerator and freezer (c) dishwasher




## 4 Design characteristics that influence energy use

All informants contributed some more explicitly than others, with different perspectives on characteristics that, in their experience, made it difficult to interact with appliances in a less energy-intensive way. Even though some characteristics were discussed more frequently for certain types of appliances, no links were found between identified characteristics and particular categories of appliances or appliances with a certain level of complexity.

This section introduces the identified characteristics and exemplifies how they influence people's energy use, and why they often impede energy conservation. Following the categorisation of layers of design proposed by Selvefors et al. (2016), the uncovered characteristics will be reviewed in relation to appliances' *communicative functions, interactive functions, and operative* functions as well as *artefact type(s)* and *enabled activity*. The interrelation between the different characteristics and potential design opportunities will be discussed in Section 5.

## *4.1 Characteristics related to an artefact's communicative functions*

The majority of informants highlighted different characteristics related to an appliance's communicative functions. Explicitness about functions, interaction possibilities and settings was identified as a key characteristic. Consumer electronics were particularly referred to and one informant shared his lack of understanding of how to turn off his laptop computer: *When I go to bed I can see that it is still on. Then I usually think: How the hell do I turn it off? But I never get around to it, it's always on* (I-73). A lack of explicitness may thus not only result in uncertainty regarding available functionality and how to use appliances in a less energy-intensive way, but also result in users not taking any actions to reduce their energy use. In contrast, appliances that are very explicit about energy efficient technology or primary energy saving features may also have negative effect on people's energy saving actions as they might limit the user's perception of all possible actions for reducing energy use. For instance, some informants using electric kettles or dishwasher eco-programs had not reflected on how to use the appliances in a less energy-intensive way, as they considered themselves to already have reduced their energy use by choosing to use these particular appliances.

Another commonly mentioned characteristic was clarity regarding an appliance's process status. A lack of status clarity may make users, for instance, keep appliances in active mode longer than needed or recharge portable devices longer just to make sure. Insufficient clarity may also make users uncertain about an appliance's current energy use, as one of the informants highlighted when talking about her dishwasher: *It is built in so I don't know if it's done or not, it doesn't have any lamp or so. It makes a sound when it finishes, but if you miss that you just don't know. I don't know if it still uses electricity, the internal lights are on, but I don't know if it's doing something* (I-34). Transparent communication regarding how an appliance and its functions contribute to energy use was also identified as important. For instance, appliances with multiple unspecified program settings made it impossible for some informants to figure out which setting is less energy-intensive. Moreover, most appliances did not communicate actual energy use in different power modes, making many informants to consider them as dishonest.

Poor communication risks resulting in users developing limited or wrong mental models of the appliances' functionality and energy use. For instance, several informants talked about how full their freezers were and that they had taken out unessential food packages to save energy, even though it is more beneficial to keep your freezer full as the frozen content keeps the cold better than air when you open the freezer door. An incorrect mental model may thus lead to actions that increase energy use instead of decreasing it.

Moreover, a limited or dishonest communication may result in a lack of trust for the product's functions and performance, which can lead to unnecessary energy use or force the user to take additional actions to make sure that no energy is used. Many informants did not trust that their appliances stopped using energy after being turned off, so they either unplugged them or used sockets with on/off switches to make sure that the power was truly cut.

### *4.2 Characteristics related to an artefact's interactive functions*

Three main characteristics were identified in relation to interactive functions: controllability, interactive clarity, and guidance. In regards to controllability, many informants appreciated good default settings and possibilities to delegate agency to the product, through for instance sleep modes or automatic shut off functions. In contrast, few appreciated a lowered level of control if the functions and settings did not match their needs or if energy use was increased. Several informants mentioned inefficient default settings that did not allow them to make adjustments. One informant described how the default setting of her printer leads to unnecessary energy use: *It turns on when I turn on the computer. So to avoid it I shut it off with the switch on the multiple socket. We do not really agree* (I-60). As she was unable to change the default setting, she was forced to manage the situation by making use of additional devices to gain control.

The informants' descriptions also highlighted that the interface and interactive elements of many appliances did not support energy efficient use or easy maintenance due to a lack of interactive clarity. The designs often made it difficult to adjust settings or loads and thereby made energy conservation impractical and difficult. A variety of product examples were identified such as TVs with small or hidden off-buttons and microwaves with complicated interfaces that made it difficult to change power settings. Moreover, some described how the design of the appliances did not support or guide them in using less energy. For instance, some informants had kettles that failed in providing appropriate guidance during filling as its indicator required the kettle to be placed horizontally for a couple of seconds in order to provide an accurate measurement. However, some exceptions were also mentioned such as the different hob sizes found on stoves, which provide visual guidance for appropriate pot sizes, and washing machines with in-built scales that indicate suitable load sizes during filling.

### *4.3 Characteristics related to an artefact's operative functions*

In regards to an appliance's operative functions, several design characteristics were identified in relation to the two sublayers. Characteristics related to an artefact's practical functions are discussed first and followed by characteristics related to an artefact's operating concept.

#### *4.3.1 Characteristics related to an artefact's practical functions*

Many informants brought up the fit, or rather the misfit, between practical functions and user needs. As all informants were single households many considered their appliances over-dimensioned and did not feel that the practical functions matched their needs. Refrigerators, dishwashers, and kettles were common examples of appliances that were perceived as too big for one person: *It's not reasonable to use the stove for making dinner for one person, for one midday meal, I think it's wasteful* (I-72); *If you heat the water in the kettle you reduce the losses, but it's a bit big, the minimum level is too much for what I normally need* (I-62).

Moreover, appliances' operability influenced the informants' motivation and opportunities for reducing energy use. For instance, appliances that the informants wanted to turn off, did sometimes not offer such functions. A typical example is the lack of an option to turn off modern televisions: *There's no direct switch, I'm still looking for it, but I don't think that I can turn the TV on or off, I have to use the remote … I have accepted that this is how it's made. In the beginning I was annoyed at it, but now I have come to terms with it* (I-22). Other appliances lacked functions for turning off specific features that were not currently in use. For instance, the same informant described how frustrated he also was with his combined refrigerator and freezer:

> "There's a combined power source for both the refrigerator and the freezer. If I want to turn one of them off I have to turn off the other as well, that annoys me. When I'm defrosting the freezer I have to turn them both off. There could have been a switch for each of them, but there isn't. Now I defrost once a year, I would probably have done it more often if I didn't have to turn the whole thing off." (I-22)

Additionally, negative consequences experienced after turning off appliances was mentioned as a reason for not turning off or unplugging certain appliances. For instance, many consumer electronics often lost track of data from on-going activities, which kept the informants from turning them off. Moreover, the informants were not at all interested in turning off appliances that provided a main function that they wanted constant access to, such as food preservation, heating, and access to Internet.

Besides the lack of operability for turning off appliances or features, some informants also talked about the lack of diversity regarding appropriate power modes. Few appliances offered power modes especially adapted to the informants' needs in particular use situations, even though some consumer electronics offered less energy-intensive power modes such as standby modes or sleep modes. Several informants had also noticed that some of their appliances, such as kettles and refrigerators, did not offer any flexibility for adjusting detailed settings. The lack of flexibility did not only make it difficult for the informants to adjust their use according to their needs, but also to influence the appliances' energy use. Exceptions such as washing machines or dishwashers with different temperatures or eco-settings were however also commonly mentioned.

### *4.3.2 Characteristics related to an artefact's operating concept*

Characteristics uncovered in relation to an appliance's operating concept were the operating concept's suitability, effectiveness and technical efficiency as well as its associated energy utilisation and performance. Some informants implicitly touched upon the operating concept's suitability and effectiveness in fulfilling particular user needs. As a particular technical approach requires a certain amount of energy, many of the informants felt incapable of influencing it when using specific appliances. Moreover, it was highlighted that certain desired outcomes often made it impossible to reduce energy use for some appliances. For instance, one informant pinpointed the microwave: *It demands a certain time and power that you can't change, it either takes longer time or leaves the food uncooked* (I-49).

In addition to the suitability and effectiveness of the operating concept, the majority of informants also discussed technical power losses and the efficiency of different appliances. Old or cheap white and brown goods were particularly referred to as inefficient while new appliances based on for example induction or LED technologies were perceived as very efficient. As many of the informants lived in rental apartments equipped with white goods, several expressed their frustration of not being allowed to switch to more efficient appliances as they considered the appliances' technical efficiency to be a vital aspect influencing the resulting energy use. Moreover, several informants described their annoyance with appliances that required energy during start-up and after use, such as cooktops and ovens that require preheating, printers with slow start-up processes, and kettles that continue to heat the water even though it is already boiling.

Some informants also described how the construction of an appliance sometimes made it difficult to benefit from all the energy being used. For instance, several informants mentioned their oven's poor energy utilisation: *My stove lets out too much heat, I would like the door to be more tight-fitting ... It radiates heat from the entire oven. The dishwasher and the sink get a bit warm, but it of course radiates from the oven door too* (I-79). Other aspects influencing an appliance's energy utilisation were also mentioned, for instance, hardware deterioration and software changes were especially highlighted for consumer electronics.

Additionally, many informants did not prioritise using their appliances in a less energy-intensive way if this would risk reducing the desired level of performance and quality. One informant described that the power saving setting of his computer significantly reduces the performance and makes the computer unusable as a gaming computer. He was thus not prepared to reduce the energy use as it would reduce the whole experience. Similarly, another informant described how his GPS sports watch made him increase his energy use to ensure performance:

> "It uses a lot of energy when the GPS is on. But even when the GPS isn't on or when it doesn't measure your pulse, the battery only lasts three days. This makes me use it less and recharge it more often. I recharge it as a preventive measure. I see it like this – as I might want to use it tomorrow, I recharge it now, even though the battery isn't dead." (I-74)

A couple of informants also highlighted how the inadequate performance associated with less energy-intensive settings in different ways increased energy use. One informant pinpointed the dishwasher: *It doesn't really get clean if the rack is packed full, so I put plates in every second slot. The plates might get cleaned at times, but I want to make sure. This means that I use it twice as much* (I-79).

## *4.4 Characteristics related to artefact type(s)*

In regards to artefact type(s), one identified characteristic concerned an appliance's usefulness, i.e. how the appliance type fit the user need in everyday life. A minor misfit may lead to an unnecessarily energy-intensive way of fulfilling the need. For instance, one informant was particularly irritated with the vacuum cleaner he used for cleaning his apartment: *That guy! It just makes noise, and uses a lot of energy. You don't need that power to suck up tiny dust particles. So when I use it, it feels like it is putting in too much effort to clean a small area* (I-81). Another informant considered it frustrating to use her electric water kettle as it was too cumbersome to manage it in daily life: *I used it a lot in the beginning, but sometimes I just don't use it. I use the stove, I don't have enough space to keep the water kettle out, it's more convenient to use a pot on the stove than to get the kettle from the high cabinet* (I-57). In contrast, a large misfit may result in the appliance being unsuccessful in fulfilling the need altogether, in which case the energy used would be wasted, or result in user rejection, in which case the appliance would not be used at all.

Another aspect that was identified in relation to artefact type(s) is the artefact's independency in relation to the artefact ecology that surrounds it when used in everyday life. Many of the informants described how their appliances encouraged the use of several products, and thereby also lead to increased energy use. The television, for example, was frequently used along with supplementary products that added functionality and improved performance: *There are so many things connected to it, a lot of other things are required which increases the* (energy) *consumption. You need these other things to get good quality* (I-73).

### *4.5 Characteristics related to the enabled activity*

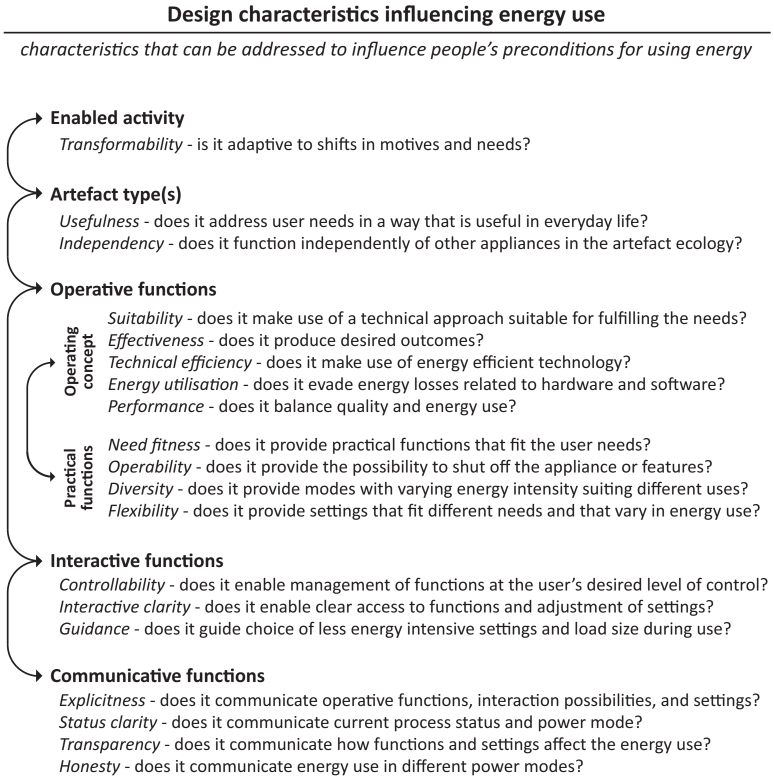
Several informants explicitly described how their use of a particular appliance changed over time as their motive for using it shifted. Even though the need activating the initial motive was still present, new motives could arise which often influenced the use of the appliance and sometimes entailed a change in activity. An increased use over time was particularly apparent for consumer electronics, such as mobile phones, which were often considered addictive and television sets that were, by some, used as a substitute for social company. Moreover, a desire to create a cosy atmosphere or build strong family traditions made many informants utilise excess lighting especially around holidays: *I love Christmas, I have my traditions. The advent lighting has to be put up; I have advent stars in all rooms, and electric advent candlesticks in all rooms* (I-54). Appliances that were still useful after a shift in needs could consequently lead to increased energy use if the new way of using the appliance was more energy-intensive way than the old way. In contrast, if an appliance proved less useful to fulfil the new need it may be replaced by another appliance.

## 5 The interrelation between characteristics

The wide range of characteristics discussed in Section 4 is summarised in Figure 2. The figure illustrates that characteristics related to functions on all layers of design set preconditions for use of appliances and energy in everyday life. The range span from characteristics related to the lower layers, such as minor communicative form details, up to the overarching layer of enabled activity. As previously exemplified, the identified characteristics highlight not only a number of potentially impeding properties but also potential mismatches between an appliance's functions and user needs in everyday life. Thus, the identified characteristics point to many different aspects that can be addressed to identify design opportunities for influencing people's preconditions for using appliances in less energy-intensive ways, see Figure 2.

Even though a specific function or characteristic can be addressed separately, it is importance to address the full range as they concern different layers of design and thus influence energy use in distinctly different ways. It is the combination of all functions and characteristics that together create the preconditions for use that influence the resulting energy use. For instance, common kettles are designed to explicitly communicate water level, offer automatic shut-off, and make use of efficient technology, but not all provide the possibility to boil a small but adequate amount of water, which makes them less effective. Addressing the lower layers without also addressing the higher layers might thus not support people in heating water in a less energy-intensive way. The higher layers need to be addressed to reduce the risk of sub-optimisation and missed opportunities for supporting energy conservation.

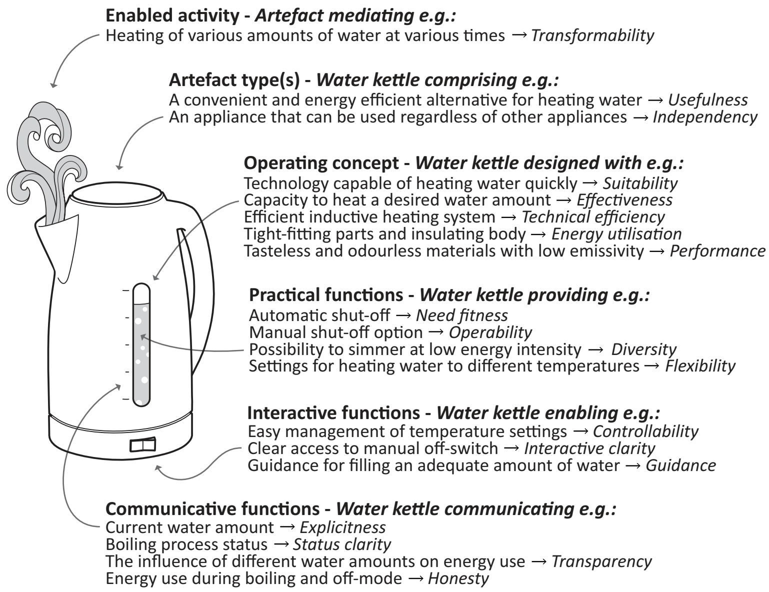
**Figure 2** Overview of the identified characteristics in relation to different layers of design




In contrast, only addressing the higher layers without also addressing the lower layers may result in unaddressed functions or characteristics impeding energy conservation. For example, if a kettle offers relevant practical functions but not the communicative qualities or interactive possibilities that would enable people to understand and make use of them, the potential for less energy-intensive use will be at risk. Thus, functions and characteristics related to all layers of design can be addressed to increase the potential for appliances that may be accepted, useful and significantly contribute to reduced energy use. Moreover, since an appliance's characteristics affect people's preconditions for interacting with the appliance in different ways, as many characteristics as possible should be considered to reduce the risk of unaddressed aspects impeding energy conservation.

An example of the variety of characteristics that could be addressed through the design of appropriate functions is highlighted in Figure 3. The figure illustrates different types of possibilities for supporting less energy-intensive ways of heating water in relation to a generic electric water kettle. This example clearly shows the need to consider the interdependence between the characteristics since a particular design opportunity related to one characteristic might conflict with a design option related to another characteristic. For example, an insulated kettle body can increase the energy utilisation but might make the boiling process less apparent and make it more difficult to estimate the current amount of water during filling. Hence, when exploring design opportunities it is crucial to consider functions and characteristics on all layers as they together create the preconditions for energy use.

**Figure 3** Examples of functions and related characteristics that may support less energy-intensive use of an electric water kettle




## 6 Discussion

The findings highlight a range of characteristics that set preconditions for people's energy use in regards to an appliance's operative, interactive and communicative functions, as well as to people's motive for using a particular appliance in everyday activities. The contribution of these findings in relation to previous research is discussed below along with implications for design and recommendations for future research.

### *6.1 Contribution of the findings*

Some of the identified characteristics are comparable to aspects highlighted in previous studies exploring how people use or perceive different appliances in relation to energy use. However, the findings contribute with new insight in three distinct ways.

First, the study uncovered more characteristics than previous studies. While other studies have, for instance, addressed honesty (Thornander et al., 2011; Zandanel, 2011), transparency (McCalley and Midden, 1998; Tang and Bhamra, 2012), explicitness (Sauer and Rüttinger, 2004; Zandanel, 2011), interactive clarity and guidance (Oberender et al., 2001; Sauer et al., 2002; Tang and Bhamra, 2012; Thornander et al., 2011), diversity

(Rodriguez and Boks, 2005), operability (Thornander et al., 2011), need fitness (Rodriguez and Boks, 2005; Tang and Bhamra, 2012), and technical efficiency (Elias et al., 2008; Oberender et al., 2001; Thornander et al., 2011), this paper emphasises additional characteristics such as performance, independency and usefulness. Moreover, even though some studies have discussed characteristics related to many of the lower and mid layers of design (see for instance Elias et al., 2009; Tang and Bhamra, 2012; Thornander et al., 2011), none has covered the wide range of design characteristics discussed in this paper. Without considering characteristics related to all layers when designing for less energy-intensive activities, the scope of design opportunities become limited, which reduces the potential for significant reductions in energy use.

Second, the findings indicate that the identified characteristics are not exclusively related to certain appliances. As discussed above, the characteristics identified in this study confirm many characteristics previously reported in studies discussing particular types of appliances. However, since the characteristics were uncovered in relation to many different types of appliances, this paper thus contributes with a more generic set of characteristics that may help identify more generally applicable design opportunities than previous research.

Third, the paper considers the characteristics in relation to their level of generality in regards to the design of an appliance by structuring the characteristics according to the layers of design proposed by Selvefors et al. (2016). While others commonly discuss one characteristic separately (see for example McCalley and Midden, 1998; McCalley et al., 2011) or several characteristics independently of each other (Thornander et al., 2011) the findings in this paper highlight the need to address the different characteristics in relation to each other as they interact to create preconditions for use. These conclusions are in line with those of Sauer and colleagues (Oberender et al., 2001; Sauer and Rüttinger, 2004; Sauer et al., 2002) that have found that the influence of on-product information on energy use does not only depend on its communicative qualities but also on its proximity to interactive elements and its ability to guide usage during interaction. Moreover, our findings highlight the importance of understanding what patterns of use a certain combination of characteristics may activate and whether it facilitates or impedes energy conservation in everyday life. For instance, the degree of controllability (for a general discussion on user control, see for instance Daae and Boks, 2014; Midden et al., 2007) that an appliance offer over practical functions not only determines the available possibilities for delegating agency but also the possibilities for satisfying needs in a less energy-intensive way during everyday life. Several informants in this study appreciated appliances for which the degree of control matched their needs and supported them to reduce their energy use. However, if an appliance in control contributed to increased energy use, the informants that were concerned about their energy use found themselves forced to find ways of regaining control of the appliance in order to be able to reduce energy use while satisfying their needs. Acknowledging and addressing the interrelation between the characteristics may thus increase the potential for supporting energy conservation more holistically.

In sum, the findings contribute to an increased understanding of relevant characteristics that can be considered in order to support energy conservation through design. From a design perspective, this is valuable as it increases the potential solution space and the potential for developing appliances that enable people to satisfy their needs while using less energy during everyday activities.

## 6.2 Implications for design

Literature on, for instance, user-centred design, usability, and human factors has proposed a number of different principles and guidelines for designing products that enable people to utilise them in a good way. For example, Stanton (1998) discusses aspects such as acceptable performance, perceived utility, and fit between functions and needs. Norman (2013) highlights, for instance, the importance of making things visible, providing affordances and constraints, as well as getting the mappings right regarding intentions, possibilities and needs. Moreover, Jordan (1998) discusses design principles such as consistency, compatibility, explicitness, and feedback.

Even though these aspects are often referred to as guidelines for designing usable products, they are less frequently discussed from a resource use perspective. As many of the characteristics identified in this study match previously proposed guidelines for usable design, we believe that they should also be considered with regards to how they support or impede energy conservation. Similar to our findings, Wever et al. (2008) highlight the importance of eliminating mismatches between delivered functionalities and desired functionalities as they may trigger unsustainable effects. They also suggest that the notion of usability can be applied to sustainable behaviour and argue that the user-centeredness of a solution for sustainability can be evaluated by assessing, not only how satisfied users are about a product, but also how effectively the side effects, arising from the use of the product, can be reduced.

The findings presented in this paper provide insight into what mismatches that may be relevant to avoid if future appliances are to enable less energy-intensive use and be appreciated by people. We agree with Jelsma (2003), who argues the importance of finding a balance between sustainability, user needs, and the design and its functions. By redesigning the material landscape (i.e. devices, appliances and systems as described by Jelsma, 2003), the environmental impact of people's everyday activities and their use of appliances may be reduced without costing them extra effort. A revised material landscape, in which new appliances and infrastructures mediate activities in alternative ways, has the opportunity to transform everyday life (cf. Jelsma, 2003; Midden et al., 2007). If addressing the range of characteristics presented in this paper during the development of appliances, new preconditions can be created that may cultivate less energy-intensive ways of living.

As discussed above, the characteristics may either support or impede energy conservation depending on how a particular design is concretised. Design decisions related to communicative, interactive, and practical functions result in a specific combination of functions that influences how a person may interact with the appliance and use it for a particular purpose. While choices regarding suitable operating concept determine, for instance, the product's energy efficiency and effectiveness, the choice of artefact type has potential for achieving even greater energy reductions as a shift may enable people to meet their needs in a new and less energy-intensive way. In order to expand the potential solutions space and create preconditions that enable people to go about their everyday activities in less energy-intensive ways, it is essential to take a holistic approach that considers the variety of design characteristics when aiming to support energy conservation from a design perspective.

### *6.3 Future research*

Even though the analysis identified a range of different characteristics that influence people's energy use, there are still characteristics to uncover. The collected data predominately points to misfits and everyday problems experienced by the informants and only a few examples of positive fits were highlighted. This is not unexpected as misfits often are tangible enough to talk about whereas positive fits most often don't result in any concrete experiences which makes them difficult for people to refer to (cf. Alexander, 1964). In order to explore additional characteristics not uncovered in this study, future studies could therefore be directed more specifically at studying aspects that make appliances fit people's needs. Moreover, as the overall study focused on single households only, future studies addressing other types of households or multiple users may identify other relevant characteristics. Additional research is also needed to further explore how the characteristics influence preconditions for use for particular types of appliances. Furthermore, comparative studies are especially needed to validate that the identified characteristics influence people's actual energy use and to assess to what extent specific designs may facilitate less energy-intensive activities.

## 7 Conclusions

This paper has highlighted a variety of design characteristics that, in different ways, influence people's preconditions for using domestic appliances in less energy-intensive ways. These characteristics will vary depending on how particular functions are concretised in the design of a specific appliance and may either support or impede energy conservation. In order to design appliances that mediate less energy-intensive activities, it is vital to consider the range of characteristics influencing people's preconditions. If addressing only one or a few characteristics, the risk of overlooking other aspects impeding energy conservation increases as well as the risk of sub-optimising and limiting the possible solution space. New opportunities for supporting energy conservation through design can be identified if the full range of characteristics, and their interrelatedness, is considered from a holistic perspective.

## Acknowledgements

The study was supported by the Climate-KIC through the flagship project Building Technologies Accelerator, as part of the research project Home Energy Management, as well as Chalmers University of Technology Areas of Advance Energy and Building Futures. The authors would like to thank the eight students at the Master's programme Industrial Design Engineering at Chalmers University of Technology for contributing to the data collection: Louise Broo, Erik Dellborg, Frida Hagelberg, Frida Johansson, Tobias Lagström, Rasmus Lindström, Julia Stensson, and Mikael Wiberg. In addition, the authors would like to thank all informants for taking part in the study.

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