(How) Can Appliances be Designed to Support Less Energy-Intensive Use? *Insights from a Field Study on Kitchen Appliances*

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This paper presents findings from a study carried out to contribute to the growing knowledge base within the Design for Sustainable Behaviour research field. Coffee makers, electric kettles and toasters were evaluated to explore if and why particular appliances may mediate less energy-intensive use to a greater extent than others. Eighteen participants used three appliances of the same type for two weeks each, during which the participants' use of the appliances and the resulting energy use were monitored. In addition, semi-structured interviews and online surveys were conducted to explore how the appliances' functions and overall design influenced energy use. The findings show that both specific functions and the design as a whole form the design characteristics that set preconditions for energy use. The study thus suggests that if appliances are not designed to support energy conservation holistically, there is a risk that aspects that have not been addressed will lead to more energy-intensive use. This makes it essential for designers to consider the full variety of characteristics influencing energy use. Based on the findings, design opportunities were identified and design guidelines formulated. The insights gained highlight new opportunities for design practice that can aid designers in designing for less energy-intensive use.

Keywords – Design for Sustainable Behaviour, Design Guidelines, Energy Conservation, Kitchen Appliances.

Relevance to Design Practice – The paper provides insights on how to design appliances in a way that supports less energy-intensive use and presents a set of design guidelines highlighting promising ways of supporting energy conservation through design.

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Introduction

Design for Sustainable Behaviour (DfSB) is a growing research field addressing sustainability challenges related to people's use of products and resources (Bhamra & Lilley, 2015). One research area commonly addressed is energy use, with a multitude of studies being carried out to explore how products can be designed to support energy conservation. Although DfSB literature suggests great potential for designing appliances to mediate less energy-intensive use, few studies have been carried out to verify these claims (see Coskun, Zimmerman, & Erbug, 2015, for an overview of DfSB studies).

So far, studies have focused on either exploring how design influences people's use of appliances (see for instance Rodriguez & Boks, 2005; Tang & Bhamra, 2012) or have assessed the potential of particular design intervention strategies, such as providing feedback or guiding use by evaluating design concepts (see for instance Oliveira, Mitchell, & May, 2016; Sohn & Nam, 2015). Few studies (see the work by Sauer and colleagues, for instance Sauer & Rüttinger, 2004; Sauer, Wiese, & Rüttinger, 2003) have assessed how design may influence energy use by systematically comparing the design of several appliances. Although Sauer and colleagues have identified many design-related aspects influencing energy use, they advise that more studies should be carried out to explore additional aspects. Moreover, the majority of their studies are laboratory experiments, highlighting the need for additional studies carried out in situ. Due to the few examples and lack of evidence of DfSB's potential, recent literature argues that additional field studies are needed to strengthen the evidence base and increase the common knowledge of what works and what does not (Boks, Lilley, & Pettersen, 2015; Coskun et al., 2015; Niedderer et al., 2014, 2016).

To contribute to the growing base of examples needed to identify promising ways of supporting energy conservation through design, a field study comparing the design of kitchen appliances was carried out. The study sought to explore if and why particular appliances may mediate less energy-intensive use to a greater extent than others in order to identify design opportunities. This paper introduces the study, presents the main findings and the identified design opportunities, then discusses the implications of the findings for design practice.

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The Field Study

The field study was designed with three test groups to evaluate three common types of kitchen appliances: coffee makers, electric kettles and toasters. The evaluated appliances, the recruitment and preparations, the procedure, data collection and analysis are described below.

The Appliances Evaluated

Nine appliances were chosen for evaluation with three products of the same type being evaluated in each of the three test groups. Care was taken to include appliances that differed in terms of complexity, level of automation and availability of functions designed to mediate less energy-intensive use. For instance, coffee maker C had an insulated jug and an automatic off function, kettle B was designed with dual chambers and an integrated filling system, toaster B had an eco-slot function for toasting one slice and toaster C had an insulating lid. Table 1 provides an overview of the appliances evaluated in each test group along with specifications and key functions.

Recruitment and Preparations

Participants were recruited by distributing invitations to single households that were frequent users of coffee makers, electric kettles or toasters respectively. Single households were targeted so that the use of the appliances could be analysed from the perspective of one individual rather than multiple users. As single households are growing in numbers, they were also considered an important target group to address. Frequent users of coffee makers were recruited to the first test group (HC), frequent users of electric kettles and toasters were recruited to the second (HK) and third (HT) test group respectively. In total, 18 households volunteered and six households were allocated to each test group. The participants' ages ranged between 29 and 91 years (Median = 48.5 years) and a majority (72%) were female. The incentive to participate was the option to keep one of the appliances evaluated at the end of the study.

All appliances were tested and prepared according to the instructions in the manuals before the start of the study. Reference measurements of the appliances' energy use in different settings and for main loads were recorded. In addition, equipment for logging the participants' use of the appliances and measuring the energy use for each event during the study was also set up. For each household, three energy meters (Philio Z-Wave Smart Energy Wall Plugs) were wirelessly linked to one logger unit (VeraEdge Home Controller) to ensure separate logging of data for each appliance. The logger unit was equipped with a memory card to store data locally on the unit. Energy meters were attached and fixed in series with each appliance to ensure that the energy meters were not disconnected during the study.

Anneli Selvefors is a researcher at Chalmers University of Technology in the Department of Industrial and Materials Science, Division Design & Human Factors. Her research explores design opportunities to enable and support people to live a more sustainable everyday life. In particular, she studies what implications the interplay between people and everyday designs may have from a sustainability point of view to identify how products and services can be designed to enable sustainable everyday activities and circular consumption patterns. Her Ph.D. thesis addressed how the design of artefacts influences people's energy use and how everyday activities can be mediated in less energy-intensive ways. Selvefors has a Master's degree in Industrial Design Engineering and a Ph.D. degree in Human-Technology-Design from Chalmers University of Technology.

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Procedure and Data Collection

The three groups followed the same test procedure, which included three test periods of two weeks each during which one of the three appliances was used and evaluated. The order in which the participants in each test group used the appliances was different for all participants. The test orders were determined in advance, but randomly assigned to the participants.

All appliances were delivered to the participants' homes at the start of the study along with packaging, manuals and a booklet with information about the study. The participants were briefed about the study and given instructions on when to use the different appliances. The measuring equipment was installed and initial brief interviews were conducted to gain insights into the participants' preconditions and current use of the particular type of appliance they were to evaluate.

Data on the participants' reported use and perception of the appliances were collected through online surveys tailored to the nine appliances evaluated. Each participant answered three surveys, one at the end of each test period regarding the appliance evaluated during the period. The surveys were used to capture the participants' experiences throughout the study to reduce the risk of participants forgetting specifics related to the use of a particular appliance or inaccurately attributing their experiences to the other appliances later on. The surveys primarily addressed the participants' use of the appliances and their functions, the participants' opinions regarding the appliances' design and the participants' thoughts on how well the design supported less energy-intensive use. For example, by answering multiple-choice questions the participants were asked to report whether they commonly brewed too much coffee, re-boiled water and re-toasted bread. The participants were also asked to rate the extent to which they agreed with different statements, such as whether a particular

Table 1. Appliances evaluated in the three test groups: a) Coffee makers b) Electric kettles and c) Toasters.

(a) Test group 1



	Coffee makers	***A***	***B***	***C***
Technical details	Wattage	*1080 W*	*1150 W*	*900-1100 W*
	Energy use, reference measurements	*1L brewed coffee: 97 Wh* *Min brewed coffee: 33 Wh*	*1L brewed coffee: 107 Wh* *Min brewed coffee: 38 Wh*	*1L brewed coffee: 97 Wh* *Min brewed coffee: 45 Wh*
	Capacity	*Max 1.5 L*	*Max 1.375 L*	*Max 1.2 L*
Practical functions	Dosing guide	*Fill level indicator*	*Fill level indicators*	*Fill level indicator*
	Keep warm function	*Hot plate*	*Hot plate*	*Insulated jug*
	On/Off functions	*Manual on/off*	*Manual on/off; Automatic on; Automatic off after 40 min*	*2 x manual on/off; Automatic off at process end*
	Additional functions		*Aroma function*	
Communicative functions	Fill level indicator	*Markings: Max-12-11-10-9-8-7-6-5-4-3-2*	*Large cup symbol with markings: 10-8-6-4; Small cup symbol with markings: 15-12-9-6*	*Cup symbol with two sets of markings: Max-10-8-6-4-3, and Max-15-13-11-9-7-5*
	Settings indicator	-	*Display shows current setting; Button(s) lights up to indicate active setting*	-
	Energy mode indicator	*On/Off switch turns red when On*	*Display is active and On/Off button turns red when On*	*Auto Off button turns red when On*

(b) Test group 2



	Electric kettles	***A***	***B***	***C***
Technical details	Marketed energy saving potential	-	*31% compared to others kettles*	-
	Wattage	*2200 W*	*2200 W*	*2200 W*
	Energy use, reference measurements	*0.7 L boiled water: 93 Wh* *Min boiled water: 93 Wh*	*0.7 L boiled water: 88 Wh* *Min boiled water: 32 Wh*	*0.7 L boiled water: 87 Wh* *Min boiled water: 81 Wh*
	Capacity	*Max 1.5 L; Min 0.7 L*	*Max 1.6 L, Min 0.2 L*	*Max 1.5 L; Min 0.5 L*
Practical functions	Dosing guide and filling function	*Fill level indicator*	*Fill level indicators; Dual chambers filling system*	*Fill level indicator*
	Keep warm function	-	-	*Automatic re-boil*
	On/Off functions	*Manual On; Manual Off and auto Off at end of process*	*Manual On; Manual Off and auto Off at end of process*	*Manual On; Manual Off and auto Off at end of process*
	Additional functions			*Temperature control with 37/60/80/90/100 degrees*
Communicative functions	Fill level indicator	*Markings: 1.5L max–1.0L–0.7L min*	*Fill markings: 1500ml-1400-1200-1000-800-600-400-200; Boil markings: Maxboil-700-600-500-400-MIN200mlMIN*	*Markings: 1.6L MAX-1.5L-1.0L-0.5L MIN*
	Settings indicator	-	-	*Display show current setting*
	Energy mode indicator	*Load indicator turns red when On*	*Water tank lights up in blue when On*	*Display is active and water tank lights up when On*
	Process status indicator	-	-	*Display and water tank colour show current temperature*

Table 1. Appliances evaluated in the three test groups: a) Coffee makers b) Electric kettles and c) Toasters. (continued)

(c) Test group 3



	Toasters	*A*	*B*	*C*
Technical details	Marketed energy saving potential	-	*50% if eco-slot function is used*	*25% compared to regular toasters*
	Wattage	*700 W*	*900 W*	*1000 W*
	Energy use, reference measurements	*Max browning (7): 42 Wh* *Mid browning (3.5): 36 Wh*	*Max browning (5.5): 59 Wh* *Mid browning (3): 36 Wh* *Eco-slot (5.5): 26 Wh*	*Max browning (9 & lid): 45 Wh* *Mid browning (4.5 & lid): 22 Wh* *Mid browning (4.5 no lid): 30 Wh*
	Capacity	*Two slices of bread*	*Two slices of bread*	*Two slices of bread*
Practical functions	On/Off functions	*Manual On; Manual Off and auto Off at end of process*	*Manual On; Manual Off and auto Off at end of process*	*Manual On; Manual Off and auto Off at end of process*
	Frozen bread function	*Toast rack*	*Browning setting for frozen bread*	*Frozen bread function*
	Additional functions	-	*Eco-slot function for toasting one slice; Peek and view function*	*Insulating lid; Re-heat function; Peak and view function*
Communicative functions	Browning indicator	*Markings: 1•2•3•4•5•6•7*	*Markings: 1•2•3•4•5• ∗*	*Markings: 1 2 3 4 5 6 7 8 9*
	Settings indicator	*Dial indicates current browning level*	*Dial indicates current browning level; Button lights up to indicate eco-slot setting*	*Dial indicates current browning level; Button(s) light(s) up to indicate active settings*
	Energy mode indicator	-	*Button(s) light(s) up when On*	*Button(s) light(s) up when On*

coffee maker allowed them to brew a desired amount, had functions and interactive elements that supported reduced energy use or communicated how different settings influenced energy use.

Round-up semi-structured interviews were conducted in the participants' homes at the end of the study to explore the participants' experiences of using the appliances in more detail. Three interview guides tailored to the three test groups were used, these covering the participants' use of the appliances during everyday activities, the participants' understanding and use of particular functions, perceived benefits and drawbacks of the appliances and the participants' perceptions of the appliances' energy use. Both open questions such as Can you describe your experiences of using the different appliances? Did the appliances influence your everyday life in any way; for instance, did they make anything easier or more difficult? Can you describe how you imagine the energy use of the appliances during a typical instance of use? were posed as well as specific questions related to particular appliances or functions such as Which of the coffee makers fitted your needs better? How did you go about filling the different coffee makers with water? What were your experiences of using a thermos jug instead of a glass jug? The participants were also free to elaborate on their use and understanding of the appliances at the end of the interview. The interviews lasted 70 minutes on average. All interviews were recorded and transcribed in full, except for one interview in which the participant requested that notes should be taken instead.

Analysis

Due to malfunctioning of a number of energy meters, data logged on the participants' use and electricity use could not be collected in full for all participants. As can be seen in Figures 2, 4 and 7, which present all the data logged, data for the electric kettles were lost to a greater extent than for the other types of appliances. The unfortunate data loss ruled out the planned quantitative data analysis intended both to explore variations in energy use and to assess whether significant differences could be found between appliances within each test group. Since the results of the planned quantitative analysis would have been indicative at best due to the low sample size, it was planned to supplement the other types of data collected during the study and used for triangulation purposes. Although only a limited number of full data sets were registered, the data were still considered valuable as they provided insights into the participants' use of the appliances and the resulting energy use. The data were thus interpreted qualitatively together with data from the surveys and interviews to evaluate how the design of the appliances influenced energy use.

The data from the surveys and interviews were analysed through two thematic analyses. First, the participants' use of the appliances and their experiences were analysed for each participant and each test group to gain an understanding of how common use patterns influenced energy use. The data were initially coded in relation to several themes: Use and acceptance, Fit with needs, Functions and overall design as well as Energy use. Sub-themes also emerged during the analysis. For instance, insights related to energy use were coded in regard to the participants' general approach towards energy conservation, their understanding of the appliances' energy use and their measures to reduce the appliances' energy use.

The second thematic analysis was carried out based on a categorisation proposed by Selvefors, Strömberg, and Renström (2016), which describes different types of functions that can be considered when designing an artefact. The analysis focused on operative, interactive and communicative functions (see Figure 1). Three main themes were addressed to gain insight into how the appliances' functions influenced usage and energy use for each test group: The influence of operative functions on usage and energy use; the influence of interactive functions on usage and energy use; and the influence of communicative functions on the participants' understanding of the appliances' functions and their energy use. Two additional themes were included to explore aspects influencing the participants' adoption of the appliances: the functions' potential to support the participants in satisfying needs; and fits and mismatches between the appliances' functions and the activities they enable.

A cross-case analysis was carried out to identify design characteristics observed to influence energy use across the three test groups. The findings from the second thematic analysis, regarding how the operative, interactive and communicative functions of the three types of appliances influenced energy use were compared and common characteristics were identified. Next, the extent to which the characteristics influenced energy use, either by directly increasing or decreasing energy use or by making less energy-intensive use easier or more difficult, was examined for each test group. This inquiry was repeated to review the interview, survey and energy meter data collected for each participant and by comparing the collected data to the reference measurements of the appliances' energy use.

Lastly, based on the cross-case analysis, design guidelines were formulated to support less energy-intensive use of appliances. Several guidelines were identified as especially relevant since they concerned aspects that were observed to influence energy use directly and to a major extent or to have a substantial influence on the use patterns of the majority of the participants.

Findings of the Field Study

The findings show that the participants' use of the appliances and their functions varied in all test groups and that the resulting energy use also varied between participants as well as between appliances. The key results for each test group are presented in turn.

Test Group 1: *Coffee Makers*

How often the participants (HC:s) used the coffee makers varied; some participants used them one or more times each day while others only used them during the weekends. The way in which the participants used the coffee makers also varied between appliances as well as between individuals, as did the amount of coffee the participants brewed.

Consequently, as illustrated in Figure 2, large variations in energy use were observed, showing the data per recorded brewing event. The largest variations between individuals as well as the largest variance for individuals were observed for coffee maker A. Variations in energy use were also observed between appliances for the participants. For instance, the energy use of participant HC:2 differed notably between coffee makers A, B and C.

Several reasons for the observed variations in energy use were identified in relation to the design of the three coffee makers. First and foremost, it is evident that the appliances' technical approach to keeping brewed coffee warm directly affects energy use. While the hotplates used in coffee makers A and B allowed for large variations in energy use, the insulated jug used in coffee maker C ensured that no additional energy was required after the brewing process.

Another reason for the identified variations in energy use was the appliances' level of automation. Coffee maker A has a manual on/off switch and can be kept on indefinitely, seeing some participants keep it on for a long time. In contrast, coffee makers B and C have timers restricting the maximum energy use as the appliances are automatically turned off after 40 min or directly after brewing is completed. However, the findings highlight the fact that automatic off functions do not always result in lower energy use than manual off functions. For instance, participant HC:4 described how the manual off function made her more likely to turn coffee maker A off sooner rather than later while she left coffee maker B on for a longer period since she knew it would switch off automatically if she forgot.

Types of functions that can be considered when designing an artefact

Operative functions
- **Operating concept** – *the technical approach used to provide an artefact's main function*
- **Practical functions** – *functions that determine what an artefact can be used for*

Interactive functions – *functions that allow access to and facilitate the management of operative functions*

Communicative functions
- **Semantic functions** – *functions that convey meaning and facilitate interpretation*
- **Syntactic functions** – *functions that order perceptual elements to form a whole*

Figure 1. Types of functions addressed in the second thematic analysis and the cross-case analysis.

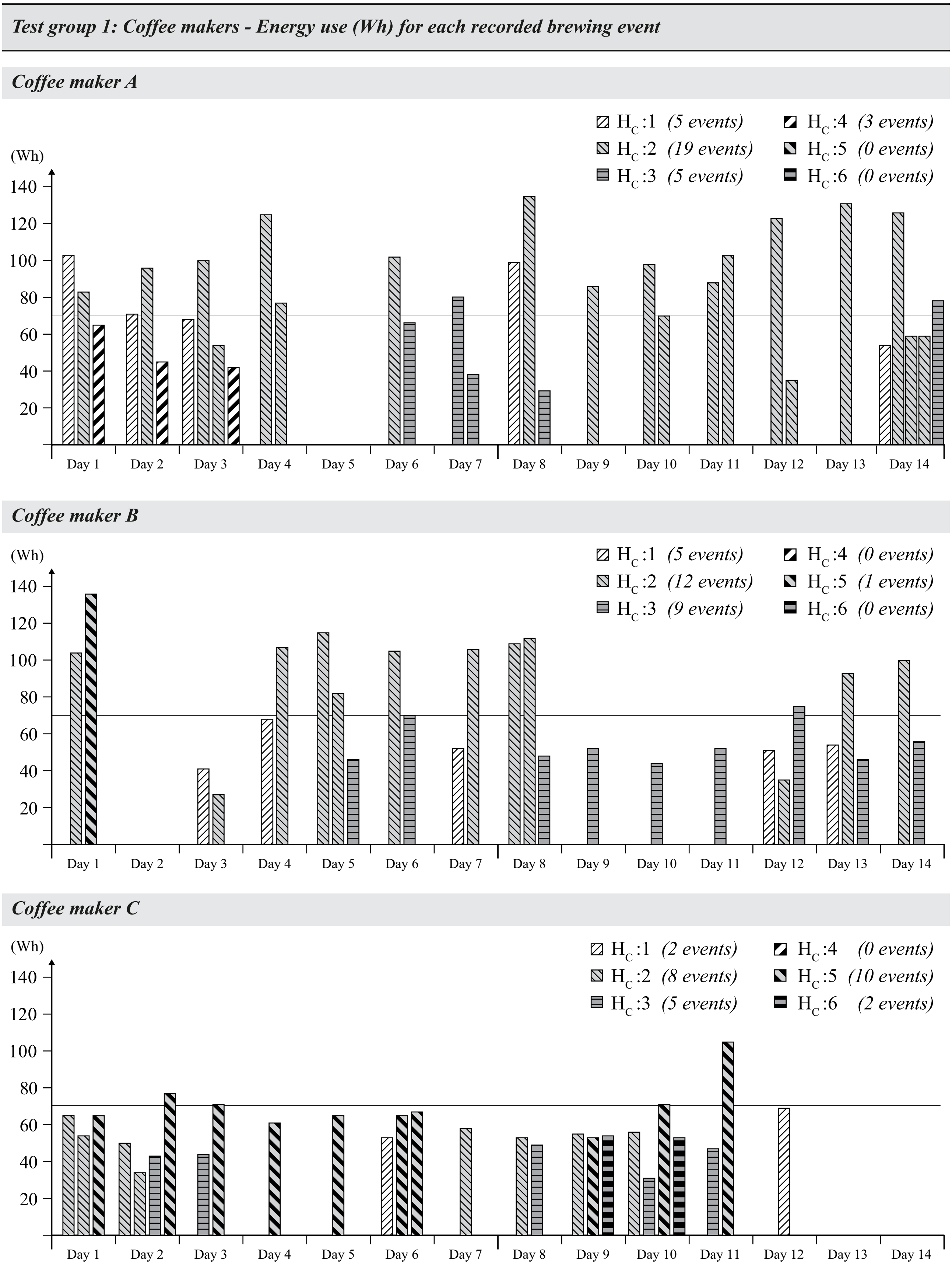


Figure 2. Energy use per recorded event for coffee makers A, B and C.

The observed variations in energy use also depended on the amount of coffee brewed, which was influenced by different aspects as shown in Figure 3. For instance, two participants considered the recommended minimum fill level, especially for coffee maker C, to be too high for their needs, which made them brew more coffee than necessary. Additionally, the majority considered the fill level indicators of coffee maker C and to some extent the indicators of coffee maker B to be inadequate in providing guidance, as the markings and symbols were unclear and confusing. Inconsistent markings on coffee maker B, which were different on the glass jug and the two sides of the water tank, added to the confusion. Some participants mentioned that they commonly chose to fill more than needed since they had found or did not trust that the volume indicated by the scale markings would be accurate. The particular designs of the water tanks also contributed to overfilling as they made it impossible to adjust the amount of water already filled and by inadequately communicating the filling of small amounts of water, which often led to a slightly larger amount than intended. Participant HC:6 also argued that the size of coffee maker A's jug made her brew more than she actually needed: "This one had an awfully big jug, so I got the impression that if I had brewed the minimum amount it would have been burnt at the bottom. So for this one I added a bit extra."

The surveys revealed that several participants considered the power mode of coffee makers B and C to be poorly communicated, making them unsure of both how different functions contributed to the energy use as well as how they should be properly turned off. Coffee maker C was especially highlighted during the interviews. For instance, participant HC:4 noted that its double set of off functions and poor access to the off switch located at the back of the coffee maker made her both uncertain and less inclined to make use of the off switch: "I turned it off at the back once or twice but otherwise I didn't bother. I'm not sure whether it still uses energy if it's not turned off at the back. ... But since it's located at the back, you really have to think about turning it off." While coffee maker A was considered to communicate power mode and energy use more distinctly than the others, several participants did not consider it, or either of the other two coffee makers, to communicate the brewing process to any greater extent. This made it difficult for the participants to know when the appliances could be turned off without unintentionally cancelling the remaining brewing process.

The participants appreciated the appliances and their functions to different extents. Two participants chose to keep coffee maker C due to the insulated jug, which made it easier for them to keep their coffee warm longer without it becoming unpalatable and also enabled them to bring the coffee to the table or balcony without it going cold. The other participants rejected coffee maker C as they often had no need to keep the coffee warm for a long time and had experienced a number of disadvantages with the insulated jug. They considered the jug heavy, difficult to clean, cumbersome to open and close and to use for filling the water tank. In addition, they did not like the jug as it made it difficult to keep track of the brewing process and the amount of coffee in the jug.

Three participants choose coffee maker B due to its glass jug, its style and additional functions although not all used them. One participant chose not to keep any of the coffee makers since the coffee maker she already owned better fitted her needs as it allowed small amounts of coffee to be brewed. Common reasons for not choosing coffee maker A were related to practical and aesthetic aspects as well as the lack of an automatic off function. Although several participants appreciated being able to turn the appliances off manually, they all considered an automatic off function to be essential for safety reasons.

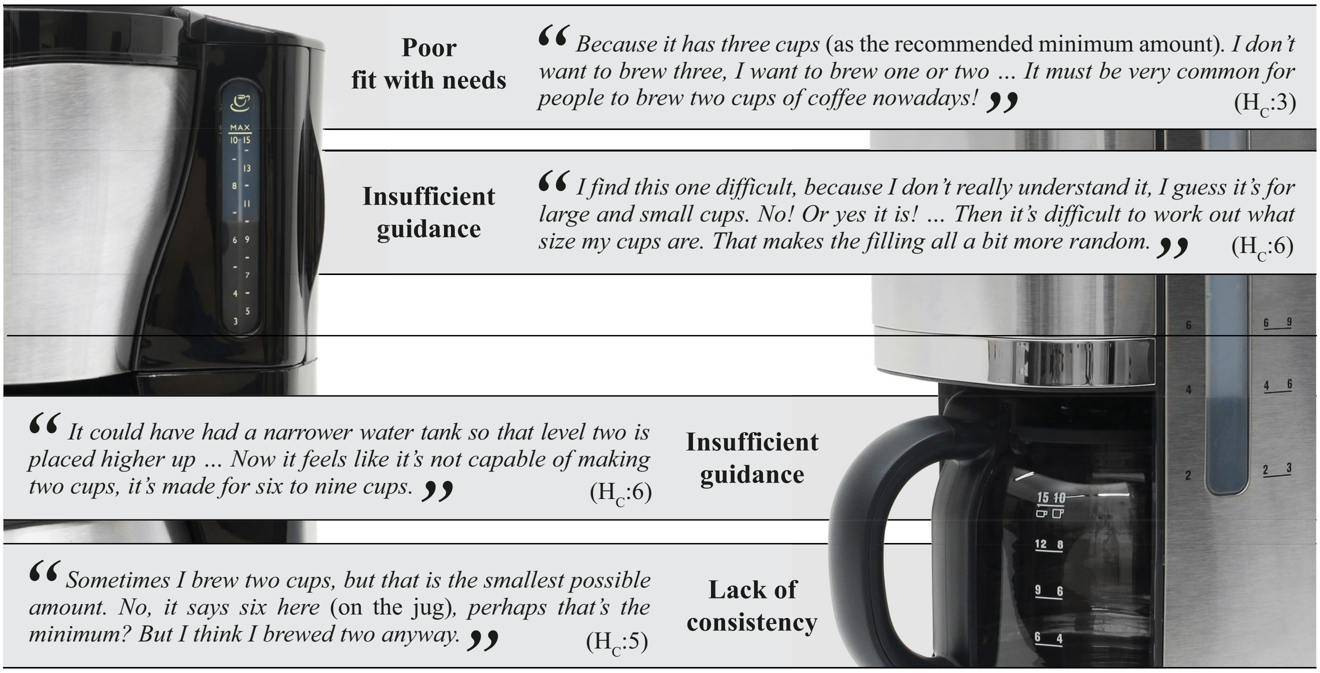


Figure 3. Examples of aspects influencing the amount of coffee brewed for coffee makers C and B.

Test Group 2: *Electric Kettles*

The interviews revealed that the participants (HK:s) used electric kettles for various activities, such as preparing hot drinks or preparing food and that the amount of water boiled commonly varied between activities and participants. As the amount of water boiled directly influences energy use, variations in energy use were observed between boiling events as illustrated in Figure 4.

Although the amount of water boiled depended on the participants' activities, the desired amount did not always coincide with the boiled amount. The participants stated that they often, or occasionally, boiled more water than needed. Overfilling of water was thus identified as the main contributing reason for unnecessary energy use. Various aspects related to the design of the kettles were observed to influence the participants' possibilities to dose according to their needs. The recommended minimum fill levels for kettle A (0.7 L) and kettle C (0.5 L) were considered too high by those who wanted to boil just enough for one cup. Participant HK:1 explained that he always disregarded the recommended levels and boiled less water, where the other participants considered it important to keep to the recommendations for safety reasons. Thus, when using kettles A and C, they always boiled the recommended level, or even higher, although they did not make use of it once boiled. In contrast, the recommended minimum fill level for kettle B (0.2 L) allowed the participants to boil according to their needs, which reduced the required energy use to 32 Wh compared to 93 Wh and 81 Wh for kettle A and C respectively when boiling the minimum amount.

All participants appreciated that kettle B provided the option to boil a small amount of water, but the kettle's integrated filling system entailed other problems (see Figure 5). The participants considered the filling system difficult to understand, cumbersome, impractical and redundant. Although the kettle offered a high level of user control, the perceived level of interaction control was low. For instance, two participants had not understood how to boil the full amount of water in the kettle, which required the opening of a valve between the dosing and the boiling chamber. Consequently, they were forced to boil half the amount twice to get the amount of water they needed. Another participant highlighted that the inadequate design of the knob used to control the valve might make people open the valve unintentionally and thus boil the full amount of water instead of a smaller amount. In addition, the integrated filling system was considered to offer only a low level of control over the outcome as it was difficult to manage in a precise way, contributing to unintentional overfilling.

The kettles' fill level indicators, designed to facilitate moderate dosing, were considered inadequate by some participants due to their type, shape and markings. For example, as the indicators were designed to show the fill level starting at the minimum recommended level, several participants explained that it was difficult to hit the minimum mark so they usually boiled slightly more. For instance, participant HK:1 argued that the design of the indicator for kettle A might make people boil too much if they did not measure the amount in advance: "You could easily get a bit more in one of these, as you do not see the water level at first. The amount does not show until it reaches 0.7 litres."

The majority appreciated kettle B's large range of indicators, although the use of double indicators confused several participants about how much water they had actually poured in. The positioning of the indicators and the need to place the kettles on a horizontal surface before reading them was also mentioned as impeding filling of an intended amount.

Another aspect influencing energy use was temperature. Several of the participants said that they often did not need the water to reach 100°C, but only participant HK:1 used to turn his kettle off before it did so automatically. Moreover, the temperature settings offered by kettle C, which could have reduced the 81 Wh required for boiling 0.5 litres to 48 Wh if the 80°C setting were used, was only used a few times by participants HK:1 and HK:6. Several aspects were highlighted that limited the participants' use of the temperature settings (see Figure 6). For instance, some considered the interactive elements of kettle C difficult to interpret and despite consulting the manual had not understood what functions they offered or how to make use of them. Others felt it was not worth the effort or simply not desirable. However, when discussing the temperature settings during the interviews, all participants saw a potential for their use even though they had not thought of it during the study. As well as preparing water for tea, baking and cooking food by making use of heated but not boiled water, were considered especially appealing.

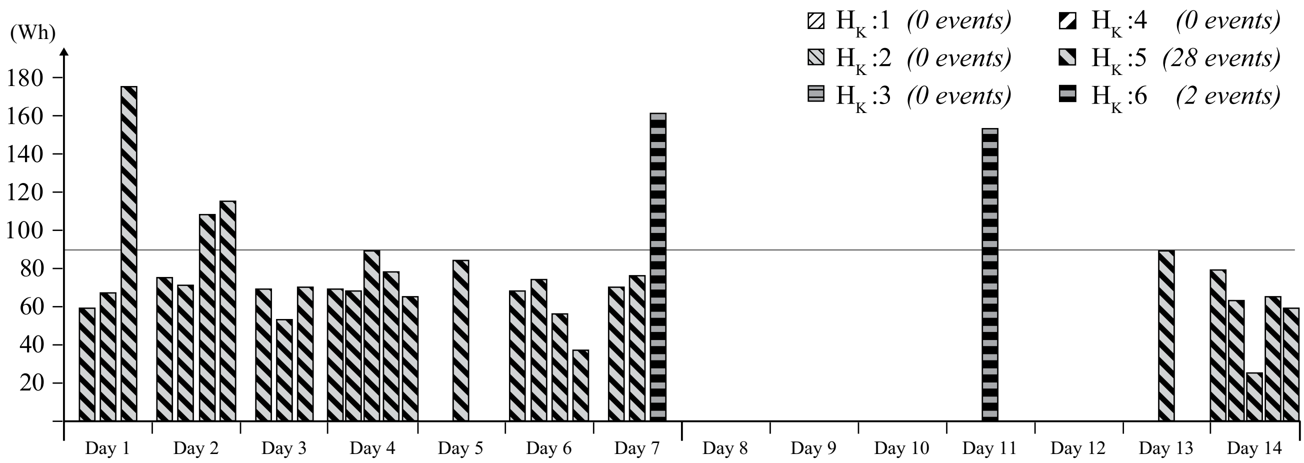
A few participants sometimes re-boiled the water to make sure it was hot enough, which contributed to increased energy use. However, although kettle C offered several functions with potential to prevent re-boils, most considered them unnecessary. Only participant HK:2 stated that the kettle's temperature indicators sometimes stopped her from re-boiling the water: "If some time passes before you go back to the kettle, you can see how hot the water is. Then you know if you need to re-boil it or not. So it's a positive thing, as it may ensure you do not boil it unnecessarily." Several participants nonetheless said that they enjoyed looking at the temperature feedback, either the light with changing colours or the display with digital numbers, which helped them to keep track of the process.

Due to the temperature feedback, all participants considered kettle C to communicate its status in a better way than the other kettles, since they only had a light indicating the on mode. Still, the participants were unsure about all the kettles' energy use and how different settings contributed to the total energy use. For instance, participant HK:4 was not entirely sure about kettle C's keep warm function: "I'm assuming that they included the keep warm function because it is less energy-intensive than boiling the water again. I hope that is the intention, that when used for 40 minutes, it does still reduce energy use."

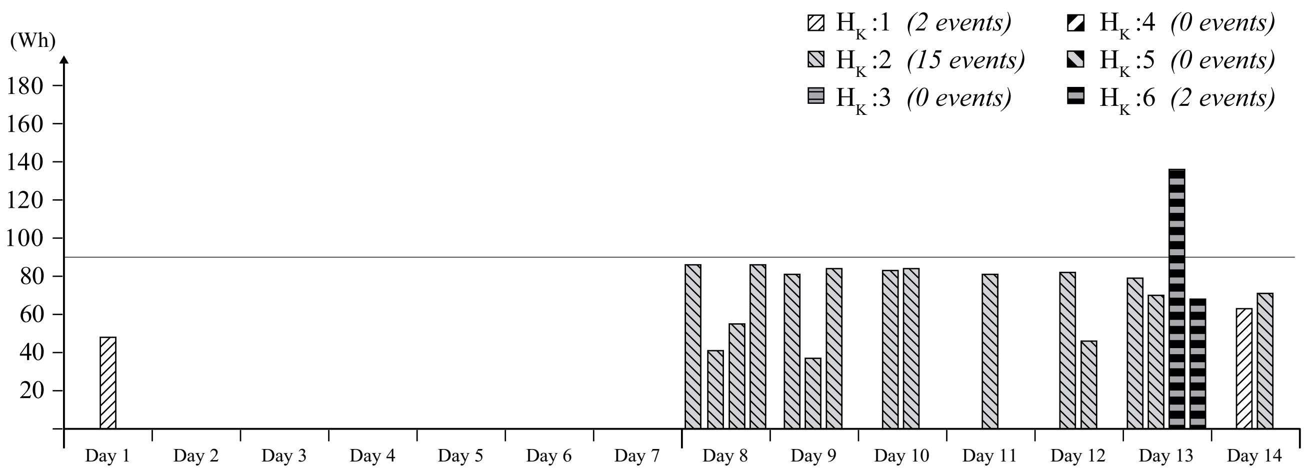
When comparing the kettles, all participants were most satisfied with kettle C as it fitted their needs and was considered more stylish than the other kettles. Its additional functions were also mentioned, although none of the participants had made use of the temperature control or its keep warm function during the study. Two participants chose to continue using their own kettle as they considered it was a better fit for their specific needs. Although kettle B was appreciated for its ability to boil small amounts

Test group 2: Electric kettles - Energy use (Wh) for each recorded boiling event

Electric kettle A



Electric kettle B



Electric kettle C

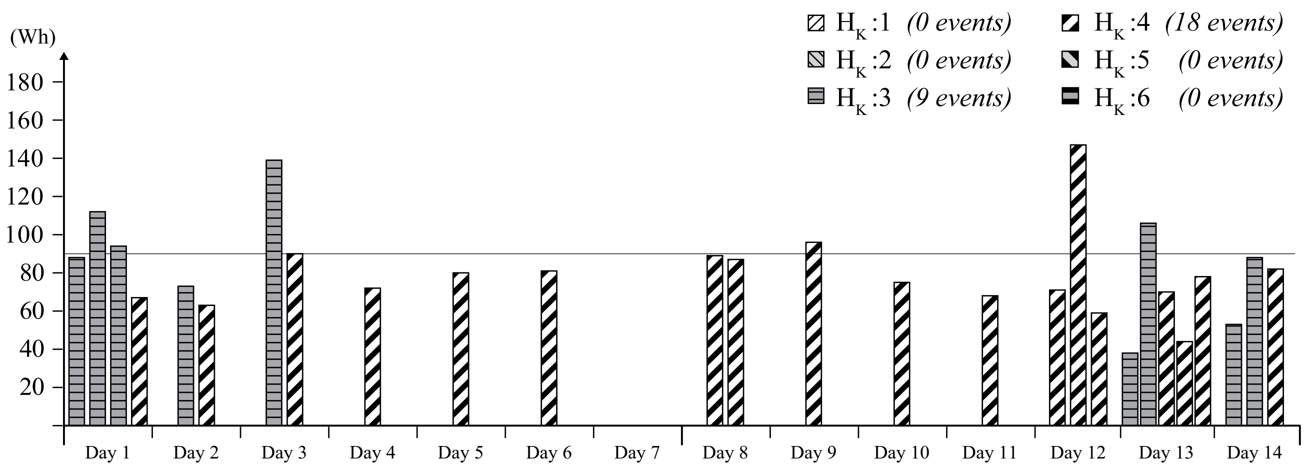


Figure 4. Energy use per recorded event for electric kettles A, B and C.

High level of user control	*"To fill the container with water you need to put it down, turn it 180 degrees, and then push the knob, which is actually quite inert and I understand why. So you really push and it makes it wobble back and forth. It can be a bit difficult to hit the minimum mark, you have to stop a bit early, but it might not get filled all the way to the mark, so you have to push some more and then there's way too much."* (H_K:4)
Insufficient guidance	*"It was difficult to get the hang of it. There were no margins, you had to press really gently but firmly."* (H_K:5)
Poor explicitness	*"I'm sure one of these indicators shows how much water is in the bottom* (boiling chamber)*, but it was not really clear to me. Is it the one at the front that shows the amount that is in the boiling chamber? ... I never really understood where you can see how much you had pushed down, it would be good to know for practical reasons."* (H_K:6)

Figure 5. Examples of aspects influencing the amount of water boiled for kettle B.

Poor fit with needs	*"How often do you really need 60-degree water? What should I use it for? Perhaps if I make instant coffee, then I can drink it straight away. That would use slightly less energy."* (H_K:3)
High level of user control	*"I think I would have to read the manual to understand how to use these* (the temperature settings)*. That's why I haven't bothered with them. ... I'm a bit lazy, I just push the button* (the on button) *to get it going."* (H_K:2)
Poor explicitness	*"The on/off is of course explicit, it will start heating the water until it reaches 100 degrees, at which point it turns off. The other two buttons are this thermometer with a plus and minus, and the mug with temperatures. I don't think it's clear which of them does what. When you have read the manual you understand the two functions, but you still don't understand which of them does what. It's really not clear to me."* (H_K:4)

Figure 6. Examples of aspects influencing the use of kettle C's temperature settings.

of water, all participants rejected it. They found it difficult to understand and interact with. It was also considered bulky to use due to its large volume and weight. Its style, materials and perceived lack of quality were other reasons expressed by the participants for rejection. Kettle A was appreciated for its simple design and speed, but was considered less attractive than kettle C.

Test Group 3: *Toasters*

The toasters were used more frequently than the other appliances and the participants (HT:s) often toasted one or more slices of bread each day. The participants used the toasters for toasting both fresh and frozen bread and for thawing frozen bread. While some liked a light crisp toast, others preferred their bread heavily toasted. The participants' use of the toasters and the resulting energy use thus varied between events and participants (see Figure 7).

The interviews provided an insight into the various ways the participants' use of the toasters influenced the energy use of specific events. For instance, the browning level and settings were often adjusted to attain the desired browning for different types of bread, which directly influenced the energy use. The participants found it difficult, however, to find a suitable browning level, which often made them soon re-toast the same slices of bread one or more times before adjusting the browning level prior to the next set of toasts. Scepticism towards toaster C due to its lid and the perceived risk of burning the bread made participant HT:6, for instance, toast her first slices of bread several times for a shorter period in order to find a suitable level. In contrast, participant HT:2 found it too tiresome to try to adjust the browning level to a suitable level when using toaster C. As shown in Figure 7, she re-toasted the bread if needed and cancelled the second round when the browning matched her preference.

Different strategies for toasting frozen bread also contributed to the observed variations. The toasters' energy use was lower when the participants had thawed the bread prior to toasting compared to strategies such as increasing the browning level, using the frozen bread settings or toasting the same slice of bread twice to ensure a good result. Moreover, toasting bread in

Test group 3: Toasters - Energy use (Wh) for each recorded toasting event (a toasting directly followed by one or more short re-toasts is vertically grouped with the re-toast(s) into one toasting event with accumulated energy use)

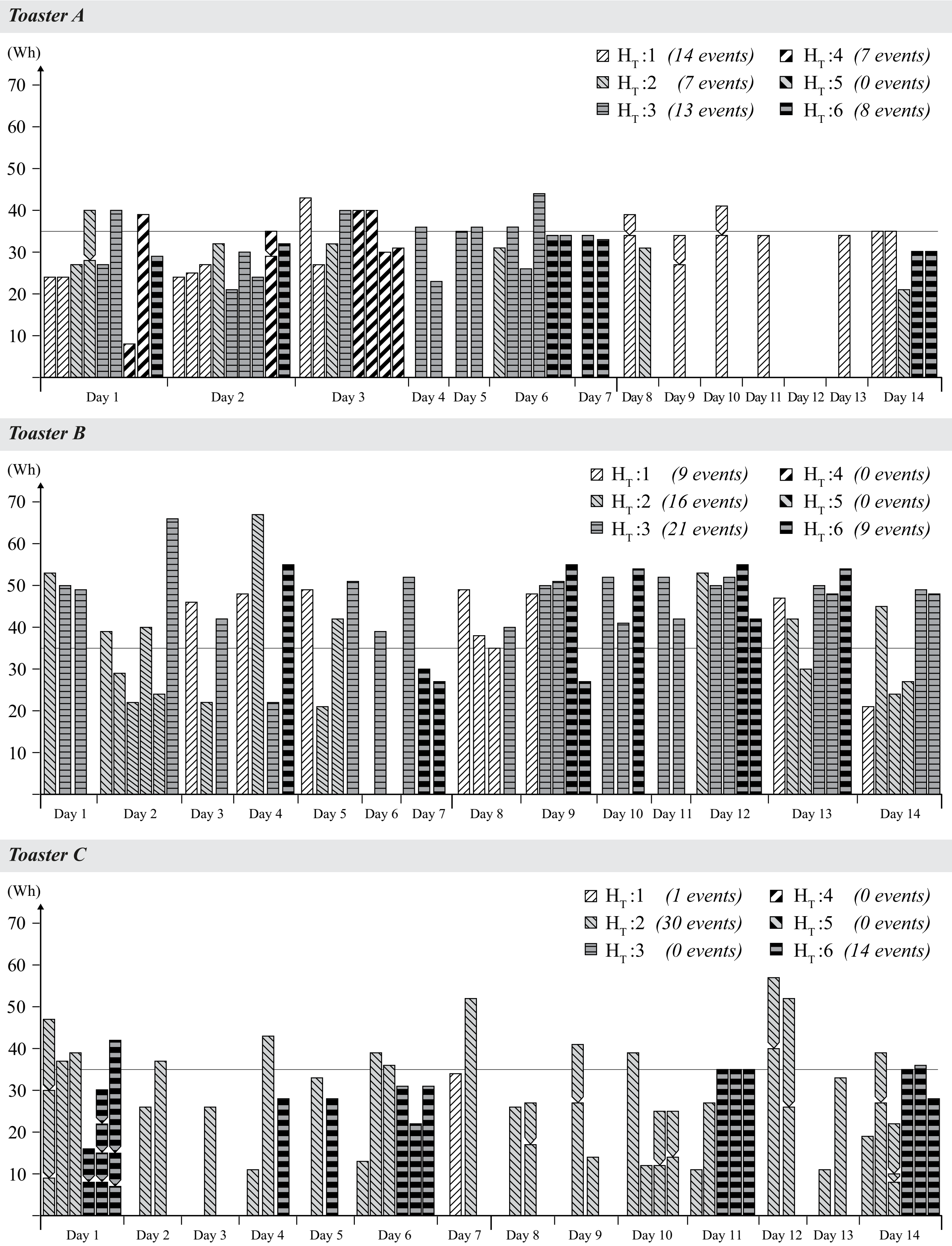


Figure 7. Energy use per recorded event for toasters A, B and C.

an already warm toaster resulted in lower energy use compared to using a cold toaster. For example, when analysing participant HT:1's use of toaster B, it was observed that toasting additional slices when the toaster was already warm required roughly 10 Wh less energy compared to toasting the first set of toast. Regarding toaster B, large differences were also observed for events in which its eco-slot function (for toasting one slice of bread) was used compared to events when it was not used. The events with lower energy use for participants HT:1, HT:2 and HT:6 were all events in which the eco-slot function was used. The energy use for these events was recorded as half that of a similar event not using the function.

Although limited, the recorded energy data also highlight slight differences between toasters. The energy use for toaster B was generally higher than the other toasters when the eco-slot function was not in use. A comparison of the toasters' energy use during controlled measurements also confirmed that toaster B requires more energy than the other toasters for the higher browning levels (see Table 1c for details). It can, however, be noted that, when in use, toaster B's eco-slot function reduces the energy use by half. Moreover, while the observed energy use of toasters A and C is similar, several participants experienced a much higher browning effect for toaster C. The higher browning effect sometimes allowed them to use a lower setting while still attaining their desired browning level, which resulted in decreased energy use.

Several aspects were highlighted as influencing the participants' use of and attitude towards the toasters (see Figure 8). For example, the participants discussed the level of control offered and all appreciated the toasters' automatic off functions. However, they considered a manual off option essential as they wanted control over the browning process, especially during re-toasting. The controllability of the toasters was also discussed in relation to toaster B's eco-slot function and toaster C's insulating lid. While the lid closed automatically, the eco-slot setting had to be chosen manually. Consequently, the eco-slot function was used only occasionally by only four participants and often forgotten in situations when it could have been used. Two participants did not notice the function at all. Several participants stated that it would have been easier to reduce energy use if the toaster automatically toasted the number of slices inserted in the toaster instead of heating both slots by default.

The participants also discussed the toasters' communicative qualities, highlighting examples that made them uncertain about the various functions of the toasters and unsure as to how to operate them correctly. For instance, unclear and confusing markings and symbols used for representing different settings made the participants uncertain about the functions available which, for some participants, resulted in more energy-intensive use than necessary. Some participants also considered the toasters, especially toasters A and B, to have indistinct markings indicating the browning level, or an inadequate range that made it more difficult for them to find an appropriate browning level.

Due to the poor communicative qualities, the participants were unsure of the toasters' energy use and the energy use of different settings. Their confidence in the marketed energy saving potential varied and their opinions differed regarding whether toaster C's lid and toaster B's eco-slot function led to reduced energy use. For example, participant HT:4 believed in toaster C's energy saving potential: "I'm convinced that it reduces energy use and it also contributes to an even browning since it limits the chimney effect." However, participant HT:6 was more doubtful

Figure 8. Examples of aspects influencing the use of toasters C and B.

about both the eco-slot function and the lid: "Only half of the heating coils are activated and the lid keeps the heat in, so at least it feels as though you are using less energy. But you don't know if that's the case."

Generally, all were satisfied with toaster B and three participants chose to keep it due to its functions, style and ease of use. Two participants chose to keep toaster C due to its multitude of functions, style and speed, and because, according to them, it produced moist yet crisp toast that was tastier than the other toasters. The other participants did not appreciate toaster C as they considered it to have unnecessary functions, to result in too moist a browning and to be impractical in size and cumbersome to use. Additionally, as the lid covered the toast, they felt that it made it more difficult to keep track of the browning process and to find a suitable browning level. One participant chose to keep using his old toaster as it enabled him to toast four slices of bread at the same time, which better suited his needs.

Cross-Case Analysis

A comparison across the test groups showed that the design of the appliances' operative, interactive and communicative functions formed particular design characteristics that set specific preconditions for use. As shown in Table 2, a number of characteristics in relation to Operative functions were identified. For instance, the appliances' ability to satisfy user needs in a frugal way was identified as a crucial characteristic since many of the participants experienced mismatches between an appliance's functions and their needs, which made them use more energy than necessary. The appliances' effectiveness, operability and level of flexibility were also identified as crucial in setting preconditions for the participants' scope to adjust their energy use. Other characteristics identified were the appliances' diversity of power modes, energy utilisation, performance and suitability of technical approaches.

Three main characteristics were identified to facilitate or impede less energy-intensive use in relation to the appliances' Interactive functions (see Table 3). The level of control the appliances provided users and the degree to which the interactive elements guided less energy-intensive use to directly influence the participants' energy use. The influence of these characteristics was, for instance, observed for kettle B, which despite its low recommended minimum fill level made filling according to needs fiddly and time consuming due to the poor design of the controls. Furthermore, the accessibility of interactive elements during use influenced the ease with which the participants could access and manage available functions. Low accessibility made less energy-intensive use more difficult.

With regard to Communicative functions, characteristics identified as influencing energy use include how accurately, consistently and explicitly information is communicated

Table 2. Design characteristics related to operative functions observed to influence energy use.

Design characteristics	*Examples of how operative functions influenced energy use*	*Test group* 1:H_C	2:H_K	3:H_T
Diversity	*Keep-warm modes requiring energy use over time increased energy use*	▲		
Effectiveness	*Default settings required more energy than needed to achieve a desired result*		▲	▲
	Settings unable to produce desired results made participants re-do the process			▲
Energy utilisation	*Insufficient insulation led to heat loss during process*			▲
	Insufficient insulation led to undesirable cooling and re-processing		▲	
Flexibility	*Functions and settings allowed adjustments of energy use*		▼	▼
	Poor possibilities for adjusting loads led to overfilling	▲	▲	
Need fitness	*Functions enabling less energy-intensive use were unwanted and/or not used*	▲	▲	▲
	A high minimum fill level led to overfilling	△	▲	
	A low minimum fill level facilitated dosing according to needs		▼	
	Design and functions not adapted to small loads led to overfilling	▲	▲	
Operability	*Automatic Off functions limited the required energy use*	▼	▼	▼
	No Off functions made participants leave them in a low power mode	▲	▲	
Performance	*Insulation increasing heat utilisation improved the quality of the result*	▽		▼
Suitability	*Functions using non-energy reliant technical approaches decreased energy use*	▼		

▲ *Observed to increase energy use or make less energy-intensive use more difficult for three or more participants*
△ *Observed to increase energy use or make less energy-intensive use more difficult for one or two participants*
▼ *Observed to decrease energy use or facilitate less energy-intensive use for three or more participants*
▽ *Observed to decrease energy use or facilitate less energy-intensive use for one or two participants*

Table 3. Design characteristics related to interactive functions observed to influence energy use.

Design characteristics	*Examples of how interactive functions influenced energy use*	*Test group* 1:H_C	2:H_K	3:H_T
Controllability	*Manual controls made participants limit energy use to what was necessary*	▽		
	High level of interaction control made less energy-intensive use cumbersome		▲	△
	Low level of user control over energy-intensive default settings led to unnecessary energy use		▲	▲
	Low level of user control over automatic Off functions with excessive delays led to unnecessary energy use	△	△	
Guidance	*Interactive elements that are difficult or fiddly to handle led to overfilling*	▲	▲	
	Interactive elements that are difficult or fiddly to handle made adjustments to less energy-intensive settings cumbersome		▲	▲
	Fill level indicators that are difficult to read during filling made it cumbersome to dose according to needs	△	▲	
Accessibility	*Few interactive elements made less energy-intensive use easy*	▽		▽
	Impractical placement of interactive elements made them difficult to see and use	▲		△
	Obscured placement of indicators made reading difficult	△	▲	

▲ *Observed to increase energy use or make less energy-intensive use more difficult for three or more participants*
△ *Observed to increase energy use or make less energy-intensive use more difficult for one or two participants*
▼ *Observed to decrease energy use or facilitate less energy-intensive use for three or more participants*
▽ *Observed to decrease energy use or facilitate less energy-intensive use for one or two participants*

(see Table 4). It was observed that due to unclear and indecipherable symbols, functions such as toaster B's eco-slot function or kettle C's temperature controls were not used or even noticed by some participants who could have benefitted from such functions. Moreover, three characteristics that influenced the participants' perception of the appliances' energy use in different ways were also identified. Firstly, how honestly the appliances communicated the current energy use, i.e., whether the communicated energy use corresponded to the actual energy use, influenced how the participants perceived the current energy use and how important they considered it to be to turn them off. Secondly, how clearly the process status and power modes were communicated was identified to influence the participants' perception of how the energy use varied throughout the usage process and in relation to different power modes as well as their perception of whether the appliances were still on or not. For instance, some participants could not tell when the process was completed so did not know when they could safely turn off the appliance without cancelling the process. Thirdly, how transparently the energy use of various functions, settings and loads was communicated influenced the participants' perception of how the current energy use may change if they made use of other functions and settings, or changed the load.

In addition to influencing energy use directly, the functions and characteristics of the appliances sometimes also gave rise to mismatches that reduced the appliances' potential to facilitate energy conservation and/or impeded adoption. For instance, as previously described, several of the participants who evaluated toaster C considered its functions unnecessary and that the lid hindered them from preparing toasts that fit their preferences. In contrast, appliances with functions that fitted the needs of the participants both facilitated energy conservation and made the appliances attractive and desirable. For example, the combination of coffee maker C's automatic off function and insulated jug enabled participants to keep their coffee warm without additional energy use, which was highly appreciated by two participants.

Identified Design Opportunities

Based on the observations of how the appliances' operative, interactive and communicative functions influenced energy use, design opportunities were identified and formulated into design guidelines (see Table 5). The suggested design guidelines point to a range of explicit design opportunities for creating functions and design characteristics that can enable and facilitate less energy-intensive use of appliances.

The cross-case analysis suggests that some functions are more central to address than others since they were observed to influence use patterns and energy use directly and to a major extent. These functions were identified to set the main preconditions for use and thus have more potential to contribute to fundamental changes in people's energy use. Especially central are functions that influence an appliance's need fitness as mismatches between functions and user needs often lead to unnecessary energy use. For instance, providing a low recommended fill level for electric kettles enables more people to boil just the amount of water needed. Making use of less energy-reliant technical approaches such as using an insulated jug to ensure that people can keep their coffee warm without using energy is also central

Table 4. Design characteristics related to communicative functions observed to influence energy use.

Design characteristics	*Examples of how communicative functions influenced energy use*	*Test group* 1:H_C	2:H_K	3:H_T
Accuracy	*Uncertainty as to how fill level markings corresponded to amount desired led to overfilling*	▲	▲	
	Low confidence in the load's correspondence to final outcome led to overfilling	△		
Consistency	*Inconsistent use of symbols and markings in comparison to commonly used symbols made them difficult to interpret which led to misuse*			▲
	Inconsistent fill level indicators made dosing confusing and increased overfilling	△	△	
Explicitness	*Fill level indicators facilitated dosing*	▼	▼	
	Explicit functions and settings alerted participants to opportunities for less energy-intensive use		▽	▼
	Unclear functions and settings made participants overlook options for less energy-intensive use	△	▲	▲
	Indecipherable utility symbols lowered use of available functions and settings		▲	▲
	Indistinguishable status of settings made it difficult to select desired settings	△		▲
Honesty	*Poor communication regarding current energy use made participants unaware of their power mode and kept appliances on longer than needed*	▲		
Status clarity	*A clearly visible power mode made participants aware of the appliances' energy use*	▼	▼	▽
	An unclear power mode made participants unsure of the appliances' energy use	▲	△	
	Visualisations of the process status made participants aware of the process		▼	
	Vague process visualisations made participants unsure as to when when the process was done and the appliance could be turned off	▲	△	
	Visualisations of the current status made participants avoid re-processing		▽	
Transparency	*Absence of information on how functions, settings and loads influence energy use made participants unsure as to how to reduce energy use*	▲	▲	▲

▲ *Observed to increase energy use or make less energy-intensive use more difficult for three or more participants*
△ *Observed to increase energy use or make less energy-intensive use more difficult for one or two participants*
▼ *Observed to decrease energy use or facilitate less energy-intensive use for three or more participants*
▽ *Observed to decrease energy use or facilitate less energy-intensive use for one or two participants*

to enabling energy conservation. Furthermore, the study indicates that an appliance's potential to support reduced energy use can be increased if its energy-intensive functions are made optional, if it offers frugal but adjustable default settings, if it provides a combination of automatic and manual turn-off functions and if it communicates its power mode and how its functions, settings and loads influence energy use.

The study clearly shows that supplementary functions intended to encourage less energy-intensive use, such as feedback on increasing temperature and detailed fill level markings, did not to any greater extent assist people in reducing their energy use if the central functions did not provide suitable preconditions. To create preconditions that significantly contribute to energy conservation, it is thus vital that the central functions influencing energy use are primarily addressed. Guidelines that target central functions and thus have higher potential to create preconditions for less energy-intensive use are emphasised with a star in Table 5. A large portion of the essential guidelines is related to an appliance's operative functions since these functions influence energy use directly and set the main preconditions for use. Nonetheless, essential guidelines are also highlighted in relation to interactive and communicative functions as these functions set preconditions for how easy it is to use and understand an appliance and its operative functions.

Although the cross-case analysis stresses the need to primarily address the central functions to create preconditions for energy conservation, the study also stresses the importance of addressing the design of appliances holistically since preconditions are created by the design as a whole. This was demonstrated for kettle B which, despite its integrated filling system and a low recommended minimum fill level, hindered the participants in filling the kettle according to their needs as the design of the interactive elements made the kettle difficult and impractical to use. The study thus revealed that if appliances are not deliberately

Table 5. Design guidelines for supporting less energy-intensive use.

	Guideline	Category
	Proposed design guidelines in relation to operative functions	
	Provide relevant power modes with different levels of energy intensity suitable for different purposes	Diversity
★	*Use default settings that require only the energy needed to achieve a desired result*	Effectiveness
	If it is important to retain heat after the process is completed, insulate relevant parts	Energy utilisation
★	*Provide functions and settings that enable adjustment of energy use*	Flexibility
	If consumables are required, allow load adjustments	
	Provide functions and settings that enable users with different preferences to achieve a desired result	Need fitness
★	*Provide settings that can be used to limit the process to what is needed in particular use situations*	
★	*If consumables are required, allow the amount or volume needed to be loaded*	
	If consumables are required, provide load containers suitable for low size or volume loads	
★	*Use automatic functions that turn the appliance off after process completed*	Operability
★	*Allow the appliance to be turned off manually*	
	Improve heat utilisation through use of insulating materials or parts	Performance
★	*Use technical approaches that are not reliant or less reliant on energy than conventional approaches*	Suitability
	Proposed design guidelines in relation to interactive functions	
★	*Make less energy-reliant functions automatic and the use of energy-intensive functions optional*	Controllability
	If a high level of interactive control is required, provide a high level of control over outcomes	
★	*Allow default settings to be adjusted*	
	Make less energy-intensive use straightforward	Guidance
★	*Guide choice of settings so that the least energy-reliant setting that leads to the desired result is chosen*	
	If consumables are required, position load indicators so that they are easy to read during loading	
	If consumables are required, position load containers so that they are easy to load	
	Limit the number of functions and interactive elements	Accessibility
	Position interactive elements so that they are easy to see	
★	*Position interactive elements so that they are easy to reach and convenient and effortless to use*	
	Position setting indicators so that they are easy to read during use	
	Proposed design guidelines in relation to communicative functions	
	If consumables are processed, clarify the resulting volume that can be expected	Accuracy
	If consumables are required, provide load indicators specifying current load	
	If load indicators are used, communicate load accurately and in a way that suits the load and appliance type	
	Use standardised or commonly used symbols and markings to communicate utility	Consistency
	If several indicators are used, make them consistent	
★	*Communicate available functions, interactive options and settings*	Explicitness
	Communicate which, and how, to use interactive elements to manually turn the appliance off	
	Mark interactive elements and settings so that the utility of all functions is clearly explained and understandable	
	If load indicators are used, allow load to be communicated through personalised markings	
	Communicate energy use	Honesty
★	*Communicate current power mode as well as any additional power modes*	Status clarity
	Make the process transparent and communicate process status	
	Make both active and inactive settings explicit	
★	*Communicate how functions, settings and loads influence energy use*	Transparency

★ *Guideline especially relevant to consider based on observations across cases in this study* designed as a whole to mediate less energy-intensive use, they risk inducing more energy-intensive use since preconditions for use are always designed, whether intended or not. Furthermore, the study clearly shows that if an appliance's overall design and combination of functions is unsuccessful in satisfying the needs and expectations of the users, it may result in people rejecting the appliance. In contrast, a design that fits the needs and complies with the preferences of the users may increase the likelihood of an appliance being chosen, appreciated and adopted, which will increase its potential to support energy conservation in the long term. Consequently, although the central functions are crucial to address in order to create preconditions for energy conservation, all guidelines may be important to implement so that the design as a whole becomes appreciated and adopted by people.

Lastly, as the different design guidelines can be implemented in the design of an appliance in different ways, it is also important to consider how to create favorable preconditions and design characteristics in each particular design case. For example, in some cases it may be suitable to communicate the energy use of an electric kettle through an on/off switch, but in other cases it may be more relevant to visualise the transfer of energy during the process (visualisation of increasing temperature) or to highlight the effects of energy use as a result of the process (boiling water).

Discussion

The aim of the study was to contribute to the growing base of examples and to identify promising ways of supporting energy conservation through design. The insights gained will therefore be discussed in comparison to previous work and in relation to what opportunities they may present to designers aiming to design for energy conservation. Since few previous studies have systematically compared the design of different appliances, the findings will also be discussed in relation to research that has explored how appliances influence people's energy use in general.

The Influence of Design on Energy Use

The study not only confirms results from previous research, but also contributes new insights into the way in which design-related aspects influence energy use. For instance, the observed influence of automated functions is in line with the findings of Sauer, Wiese, and Rüttinger (2003, 2004, 2009) who observed that automatic off functions facilitated energy savings compared to fully manual controls. Similarly, Oberascher, Stamminger, and Pakula (2011) concluded that with regard to coffee makers, an automatic off function combined with a thermos jug is an effective option both for smaller and larger volumes regardless of whether the coffee is to be kept hot for a longer period or not. Although the findings of this study are in line with these results, the present study also suggests that automatic functions may increase energy use, if, for instance, energy intensive default settings are used, which makes it essential to question when automation is beneficial for energy conservation. The findings also highlight that to attain user acceptance for automatic functions, users must have the option of overriding defaults or automatic functions if needed. Hence, the study advocates that appliances should be designed with functions that balance manual control and autonomy in a way that facilitates less-energy intensive use. This claim is in line with literature that argues for adjustable autonomy (see e.g., Scerri, Pynadath, & Tambe, 2002), which discusses different strategies to transfer decision-making control between technology and people.

Findings regarding different aspects influencing the dosing of water, both for coffee makers and electric kettles, are to some extent consistent with previous studies. While supporting claims by Sauer and Rüttinger (2004) that improved scale markings and transparency may assist people to fill according to their needs, the findings show that a double reservoir kettle, as recommended by Sauer et al. (2003), does not. On the contrary, the findings show that such a design may inhibit people from filling according to needs, increase physical effort and lead to rejection. In order to facilitate less energy-intensive use, this study instead suggests that lowering the recommended minimum fill level is crucial as too high a level may force people to fill more than they need.

Similar to the findings of this study, poor communication of functions and settings plus impractical positioning of interactive elements have been highlighted in literature as other aspects that influence energy use. Poor design may impede energy conservation not only by making appliances and functions difficult to understand (cf. Oliveira et al., 2016; Sauer, Rüttinger, & Rüttinger, 2000; Zandanel, 2011) and difficult to interact with (cf. Tang & Bhamra, 2012; Zandanel, 2011), but also by making the energy use of appliances and different settings unclear (cf. Oliveira et al., 2016; Zandanel, 2011). If appliances are designed to aid understanding and use, energy conservation may instead be facilitated. For instance, Sauer, Wiese, and Rüttinger (2002) observe positive effects of aspects such as enhanced labelling, visibility of labelling and proximity of controls.

Identifying mismatches between available functions and relevant functions as another reason why people may use appliances in a more energy intensive way is not unique to this study. Jensen, Strengers, Kjeldskov, Nicholls, and Skov (2018) identified that smart home devices designed with functions that do not correspond to people's current needs, but are nonetheless considered desirable, often increase people's energy demand and energy use as they give rise to new needs when people use and appropriate them in everyday life. Others have observed that the lack of relevant and desirable functions will increase energy use for appliances such as TVs (Rodriguez & Boks, 2005), vacuum cleaners (Sauer et al., 2002), refrigerators (Tang & Bhamra, 2012) and coffee makers (Thornander, Karlsson, & Bakker, 2011). The findings of this study, however, indicate that mismatches not only influence energy use, but also the extent to which people may appreciate, use and adopt appliances designed to facilitate less energy-intensive use. If appliances are designed with less energy-reliant functions that are relevant and useful for people, less energy-intensive use will be enabled and the potential for contributing to energy conservation in the long term would increase. Hence, the challenge is to design desirable appliances that embed energy conservation in everyday life (cf. Jensen et al., 2018).

Implications for Design Practice

This study clearly highlights the potential for and importance of addressing how appliances can be designed to support less energy-intensive use in line with DfSB research. However, the findings also provide a number of implications for design practice.

First of all, this paper introduces a larger variety of guidelines that can be used to address a wider range of functions and characteristics compared to previously suggested guidelines (see for instance Brezet & Van Hemel, 1997; Sauer et al., 2003; Telenko & Seepersad, 2010; Telenko, Seepersad, & Webber, 2008; Thornander et al., 2011). The proposed guidelines provide designers with a larger palette of opportunities for supporting less energy-intensive use and also identify guidelines especially relevant to consider in order to address central functions that can create preconditions for energy conservation (see Table 6). Although the range of guidelines and the recommendations are based on insights gained in this study in regard to coffee makers, electric kettles and toasters, the suggested guidelines are formulated in a way that points to opportunities to create favorable functions and design characteristics for appliances in general. It can thus be argued that the proposed design guidelines and recommendations provide a better starting point for designers than previously suggested sets of guidelines.

As illustrated in Table 6, some of the guidelines especially recommended coincide with previously suggested guidelines. For instance, allowing an appliance to be turned off manually has been argued for extensively, for example by Thornander et al. (2011), Brezet and Van Hemel (1997), and Telenko et al. (2008). However, to the authors' knowledge, five of the guidelines emphasised as especially relevant to consider have not been suggested previously. These include guidelines that tackle: load amount and volume; the balance between automatic and optional functions; choice guidance during use; the positioning of interactive elements; and the communication of power modes. Since these guidelines target central functions that have been identified to influence use patterns and energy use directly and to a major extent, they present an important contribution that can aid designers to more easily target specific functions that influence energy use.

In addition to suggesting guidelines, this paper also argues for taking a systems perspective on the design of appliances. Focusing solely on one or more central functions will not be sufficient to ensure less energy-intensive use since the design as a whole or specific functions that are left unaddressed might give rise to design characteristics that impede energy conservation (cf. Selvefors et al., 2016). Hence, it is important to consider the full range of guidelines in each particular design case and not merely the guidelines highlighted as especially relevant. Moreover, as the relevance and applicability of the proposed design guidelines will likely vary for different types of appliances, a systems perspective also ensures that all relevant functions will be addressed in each case. These insights are in contrast to arguments presented by, for instance, Elias, Dekoninck, and Culley (2009b), Faiers, Cook, and Neame (2007) and Sauer and Rüttinger (2004), who all claim that addressing supplementary functions is of little value. This claim is problematic as it overshadows the importance of considering how the interrelatedness of functions and design characteristics influence energy use.

Failing to address the design as a whole may not only impede energy conservation but can also make people reject an appliance, in which case its potential to support energy conservation is lost. It is thus necessary to design appliances in a way so that they are relevant, useful and appreciated by people. If an appliance is not designed from a systems perspective it increases the risk of mismatches between the functions and the needs of the user, which can make the appliance undesirable to use or challenging to use in a less energy-intensive way (cf. Selvefors, 2017). An unfortunate lack of a systems perspective is evident in many studies, which have resulted in concepts that have a high risk of being rejected (see for example studies by Broms et al., 2010, Cowan, Bowers, Beale, and Pinder, 2013 and Oliveira et al. 2016). Contrary to these studies, this study argues that it is imperative to address the design and its characteristics holistically to increase the potential for an appliance to both mediate less energy-intensive use and be adopted in everyday life. Due to the diversity of user needs and use situations, considering the needs and preferences of the intended users through people-centred design processes (see for instance Abras, Maloney-Krichmar, & Preece, 2004) is thus essential.

Additionally, as Sauer et al. (2003) and Telenko and Seepersad (2010) argue, the design and choice of functions should always be justified from a product life-cycle perspective so that the functions and their use contribute to a total net reduction in terms of environmental impact.

Future Research

To validate the findings and identify other relevant guidelines, additional field studies should be carried out to further evaluate the design of coffee makers, kettles and toasters as well as additional types of appliances. It would be particularly relevant to study appliances designed and marketed to facilitate energy conservation. Increased sample sizes, in situ observations and detailed energy measurements would be beneficial to assess the influence of particular functions on energy use in greater detail. Analysing appliances' energy use in relation to their theoretical minimum and intrinsic and user-related losses, as suggested by Elias et al. (2009a), can also be useful in identifying whether addressing technical aspects or use-related aspects for a particular type of appliance has higher potential to result in significant reductions.

Future field studies aimed at collecting quantitative data on energy use should ensure a research procedure that reduces the risk of data loss. The preventive actions carried out in this study, such as pilot testing the equipment at several locations, attaching a separate wall plug to each appliance, storing data locally, conducting the installation of all measurement equipment and providing detailed instructions to the participants, can all help to reduce the risk. Moreover, the preparation phase should allow

Table 6. Proposed design guidelines compared to previously suggested guidelines.

	Proposed design guidelines for supporting less energy-intensive use of appliances		*Comparison with literature*				
			Brezet & Van Hemel (1997)	*Sauer et al. (2003)*	*Telenko & Seepersad (2010)*	*Telenko et al. (2008)*	*Thornander et al.(2011)*
Operative functions	*Provide relevant power modes with different levels of energy intensity suitable for different purposes*		◇		◇	◇	
	Use default settings that require only the energy needed to achieve a desired result	★				◆	◆
	If it is important to retain heat after the process is completed, insulate relevant parts		◆				
	Provide functions and settings that enable adjustment of energy use	★			◆		
	If consumables are required, allow load adjustments						
	Provide functions and settings that enable users with different preferences to achieve a desired result						
	Provide settings that can be used to limit the process to what is needed in particular use situations	★		◆		◆	
	If consumables are required, allow the minimum amount or volume needed to be loaded	★					
	If consumables are required, provide load containers suitable for low size or volume loads						
	Use automatic functions that turn the appliance off after process completed	★		◆			◇
	Allow the appliance to be turned off manually	★	◆			◆	◆
	Improve heat utilisation through use of insulating materials or parts				◇	◇	
	Use technical approaches that are not reliant or less reliant on energy than conventional approaches	★	◇			◇	◆
Interactive functions	*Make less energy-reliant functions automatic and the use of energy-intensive functions optional*	★					
	If a high level of interactive control is required, provide a high level of control over outcomes						
	Allow default settings to be adjusted	★		◆			
	Make less energy-intensive use straightforward					◆	◆
	Guide choice of settings so that the least energy-reliant setting that leads to the desired result is chosen	★					
	If consumables are required, position load indicators so that they are easy to read during loading						
	If consumables are required, position load containers so that they are easy to load						
	Limit the number of functions and interactive elements						
	Position interactive elements so that they are easy to see						
	Position interactive elements so that they are easy to reach and convenient and effortless to use	★					
	Position setting indicators so that they are easy to read during use						
Communicative functions	*If consumables are processed, clarify the resulting volume that can be expected*						
	If consumables are required, provide load indicators specifying current load		◇	◇		◇	
	If load indicators are used, communicate load accurately and in a way that suits the load and appliance type			◇			
	Use standardised or commonly used symbols and markings to communicate utility						
	If several indicators are used, make them consistent						
	Communicate available functions, interactive options and settings	★		◇			
	Communicate which, and how, to use interactive elements to manually turn the appliance off						
	Mark interactive elements and settings so that the utility of all functions is clearly explained and understandable		◇				
	If load indicators are used, allow load to be communicated through personalised markings						
	Communicate energy use					◆	◆
	Communicate current power mode as well as any additional power modes	★					
	Make the process transparent and communicate process status			◇	◆		
	Make both active and inactive settings explicit						
	Communicate how functions, settings and loads influence energy use	★		◇			◇

★ *Guideline especially relevant to consider based on observations across cases in this study*
◆ *Previously proposed guideline formulated in a similar way*
◇ *Previously proposed guideline formulated in a different way but with similar meaning*

for extensive and extended testing of the equipment to prevent unexpected measurement equipment malfunctioning over time. Using equipment that does not rely on wireless data transfer is also recommended.

Research is also needed to explore to what extent the insights may support design practice and to assess the usefulness and potential of the suggested design guidelines to reduce energy use. Consequently, case studies exploring how less energy-intensive use can be supported by designing and evaluating concepts based on the insights presented in this paper would be valuable additions to the growing collection of DfSB studies.

Conclusion

The field study was carried out to explore if and why appliances may differ in the extent to which they mediate less energy-intensive use. The findings show that the design of the evaluated appliances set preconditions for use that influenced whether energy conservation was supported or not in particular use situations. The appliances that were found to facilitate less energy-intensive use to a larger extent than the others had a combination of functions that created favourable design characteristics, such as suitability, operability and flexibility. The fit between functions and user needs was identified as another crucial characteristic. Mismatches did not only make appliances impede energy conservation, but also increased the risk of rejection. The participants rejected the appliances they considered had irrelevant functions or an inadequate design, which was observed also for appliances designed with specific functions to reduce energy use. The study thus demonstrates the need for a holistic perspective through which an appliance's design as a whole and its combination of functions are addressed to create preconditions that enable less energy-intensive use and also increase the potential for adoption.

To aid design practitioners to apply such a systems perspective, a set of design guidelines is suggested. The guidelines target a range of different functions and provide a larger palette of opportunities than previously suggested sets of guidelines, which will hopefully increase the awareness of the range of aspects that can be considered in order to address issues of energy conservation in design practice. Hence, the findings do not only present valuable insights that add to the growing DfSB evidence base, but also highlight promising new ways of supporting energy conservation through design.

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References

1. Abras, C., Maloney-Krichmar, D., & Preece, J. (2004). User-centered design. In W. Bainbridge (Ed.), *Encyclopedia of human-computer interaction* (pp. 445-456). Thousand Oaks, CA: Sage.
2. Bhamra, T., & Lilley, D. (2015). IJSE special issue: Design for Sustainable Behaviour. *International Journal of Sustainable Engineering, 8*(3), 146-147.
3. Boks, C., Lilley, D., & Pettersen, I. N. (2015). The future of design for sustainable behaviour, revisited. In M. Matsumoto, K. Masui, S. Fukushige, S. Kondoh (Eds.), *Sustainability through innovation in product life cycle design* (pp. 675-689). Singapore: Springer. https://doi.org/10.1007/978-981-10-0471-1_46
4. Brezet, H., & Van Hemel, C. (1997). *Ecodesign: A promising approach to sustainable production and consumption*. Paris, France: United Nations Environment Programme.
5. Broms, L., Katzeff, C., Bång, M., Nyblom, Å., Ilstedt, S. H., & Ehrnberger, K. (2010). Coffee maker patterns and the design of energy feedback artefacts. In *Proceedings of the 8th Conference on Designing Interactive Systems* (pp. 93-102). New York, NY: ACM.
6. Coskun, A., Zimmerman, J., & Erbug, C. (2015). Promoting sustainability through behavior change: A review. *Design Studies, 41* (Part B), 183-204.
7. Cowan, B. R., Bowers, C. P., Beale, R., & Pinder, C. (2013). The stroppy kettle: An intervention to break energy consumption habits. In *Proceedings of the Conference on Human Factors in Computing Systems* (pp. 1485-1490). New York, NY: ACM.
8. Elias, E. W. A., Dekoninck, E. A., & Culley, S. J. (May 5, 2009a). *Quantifying the energy impacts of use: A product energy profile approach.* Paper presented at the Conference on Life Cycle Engineering, Cairo, Egypt. Retrieved from https://core.ac.uk/download/pdf/2802403.pdf
9. Elias, E. W. A., Dekoninck, E. A., & Culley, S. J. (2009b). Designing for 'use phase' energy losses of domestic products. In Proceedings of the Institution of Mechanical Engineers, Part B: *Journal of Engineering Manufacture* (Vol. 223(1), pp. 115-120). https://doi.org/10.1243/09544054JEM1295
10. Faiers, A., Cook, M., & Neame, C. (2007). Towards a contemporary approach for understanding consumer behaviour in the context of domestic energy use. *Energy Policy, 35*(8), 4381-4390.
11. Jensen, R. H., Strengers, Y., Kjeldskov, J., Nicholls, L., & Skov, M. B. (2018). Designing the desirable smart home: A study of household experiences and energy consumption impacts. In *Proceedings of the Conference on Human Factors in Computing Systems* (No. 4). New York, NY: ACM.
12. Niedderer, K., Ludden, G., Clune, S., Lockton, D., Mackrill, J., Morris, A., Gutteridge, R. (2016). Design for behaviour change as a driver for sustainable innovation: Challenges and opportunities for implementation in the private and public sectors. *International Journal of Design, 10*(2), 67-85.

13. Niedderer, K., MacKrill, J., Clune, S., Evans, M., Lockton, D., Ludden, G., …Cain, R. (2014). Joining forces: Investigating the influence of design for behaviour change on sustainable innovation. In *Proceedings of NordDesign Conference* (pp. 620-630). Aalto, Finland: Aalto Design Factory.
14. Oberascher, C., Stamminger, R., & Pakula, C. (2011). Energy efficiency in daily food preparation. *International Journal of Consumer Studies, 35*(2), 201-211.
15. Oliveira, L., Mitchell, V., & May, A. (2016). Reducing temporal tensions as a strategy to promote sustainable behaviours. *Computers in Human Behavior, 62*, 303-315.
16. Rodriguez, E., & Boks, C. (2005). How design of products affects user behaviour and vice versa: The environmental implications. In *Proceedings of the 4th International Symposium on Environmentally Conscious Design and Inverse Manufacturing* (pp. 54-61). Tokyo, Japan: Union of EcoDesigners.
17. Sauer, J., & Rüttinger, B. (2004). Environmental conservation in the domestic domain: The influence of technical design features and person-based factors. *Ergonomics, 47*(10), 1053-1072.
18. Sauer, J., Rüttinger, B., & Rüttinger, B. (2000). A new framework for the design of ecological domestic appliances: Design-centred product development. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (pp. 6-319-6-322). New York, NY: Sage.
19. Sauer, J., Wiese, B. S., & Rüttinger, B. (2002). Improving ecological performance of electrical consumer products: The role of design-based measures and user variables. *Applied Ergonomics, 33*(4), 297-307.
20. Sauer, J., Wiese, B. S., & Rüttinger, B. (2003). Designing low-complexity electrical consumer products for ecological use. *Applied Ergonomics, 34*(6), 521-531.
21. Sauer, J., Wiese, B. S., & Rüttinger, B. (2004). Ecological performance of electrical consumer products: The influence of automation and information-based measures. *Applied Ergonomics, 35*(1), 37-47.
22. Sauer, J., Wiese, B. S., & Rüttinger, B. (2009). The utilisation phase as a critcal element in ecological design. In M. S. Hundal (Ed.), *Mechanical life cycle handbook: Good environmental design and manufacturing.* New York: Marcel Dekker.
23. Scerri, P., Pynadath, D. V., & Tambe, M. (2002). Towards adjustable autonomy for the real world. *Journal of Artificial Intelligence Research, 17*, 171-228.
24. Selvefors, A. (2017). *Design Beyond Interventions – Supporting Less Energy-reliant Activities in the Everyday* (Doctoral dissertation). Chalmers University of Technology, Gothenburg, Sweden.
25. Selvefors, A., Strömberg, H., & Renström, S. (2016). What a designer can change: A proposal for a categorisation of artefact-related aspects. In *Proceedings of DRS2016: Design + Research + Society - Future-Focused Thinking, Volume 4* (pp. 1339-1355). London, UK: Design Research Society.
26. Sohn, M., & Nam, T. -J. (2015). Understanding the attributes of product intervention for the promotion of pro-environmental behavior: A framework and its effect on immediate user reactions. *International Journal of Design, 9*(2), 55-77.
27. Tang, T., & Bhamra, T. (2012). Putting consumers first in design for sustainable behaviour: A case study of reducing environmental impacts of cold appliance use. *International Journal of Sustainable Engineering, 5*(4), 288-303.
28. Telenko, C., & Seepersad, C. C. (2010). A methodology for identifying environmentally conscious guidelines for product design. *Journal of Mechanical Design, 132*(9). doi:10.1115/1.4002145
29. Telenko, C., Seepersad, C. C., & Webber, M. E. (2008). A compilation of design for environment principles and guidelines. In *Proceedings of International Conference on Design Engineering Technical & Computers and Information in Engineering* (pp. 289-301). New York, NY: ASME.
30. Thornander, S., Karlsson, I. C. M., & Bakker, C. (2011). Predicting energy thieves. In *Proceedings of 16th International Conference on Sustainable Innovation towards Sustainable Product Design* (pp. 193-201). Farnham, UK: The Centre for Sustainable Design.
31. Zandanel, A. (2011). Users and households appliances: Design suggestions for a better, sustainable interaction. In *Proceedings of the 9th Italian Chapter International Conference on Computer-Human Interaction* (pp. 96-100). New York, NY: ACM.