FIRING UP SUSTAINABLE BEHAVIOUR

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Abstract

For many products there is a substantial potential for reducing environmental impacts by altering the way people interact with them. The current work investigates the potential for improving the way people interact with woodstoves, thereby reducing the environmental impact resulting from burning firewood, by adjusting the design of the woodstove. The paper describes a complete user centred Design for Sustainable Behaviour process, from initial ethnographic studies, through the design process, to a comparative testing of a prototype and a regular woodstove monitoring emissions and user behaviour. The test indicates that the prototype is used much more in line with the recommendations and emitted 35% less particles than the conventional stove, and thus indicates the successfulness of the applied approach.

Keywords: Human Behaviour in Design, Ecodesign, User centred design, Design for Sustainability, Woodstove emissions

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1 INTRODUCTION

Design for Sustainable Behaviour is a research field that explores design strategies for reducing behaviour-related environmental impacts of product and systems as well as more general applications to persuade users into more socially desirable behavioural patterns (Lockton et al., 2010; Elias, 2011; Wilson, 2013; Pettersen and Boks, 2009). DfSB research incorporates insights from scientific fields including social psychology, persuasive technology, sustainable consumption, stakeholder analysis and interaction design. The potential for reducing environmental impacts that are a result of users' interaction with products has been investigated and analysed in an increasing number of case studies for products such as refrigerators and mobile phones (Lilley, 2009; Tang and Bhamra, 2012). To date, no case studies exist that focus on spatial heating by burning of firewood in woodstoves. For countries like Norway, emissions from this practice represent a significant environmental impact. In Norway, about 72% of the households have access to a woodstove (SSB, 2011a) and 57% actively use it as a heating source (Haakonsen and Kvingedal, 2001). In total, burning of firewood provides 17% of the total energy consumed by Norwegian households (SSB, 2011a).

Burning firewood as an energy source has a low environmental impact compared to electricity with the average Nordic electricity mix (Solli et al., 2009), which is the most commonly used energy source for heating in Norway and provides 78% of the energy consumption of the households (SSB, 2011a). It has long been assumed that firewood is carbon neutral as the amount of CO_2 released when burned is assimilated during growth (Bright et al., 2012). This is not entirely correct due to the emissions related to production and transportation of the firewood (Solli et al., 2009). It is also incorrect to assume that carbon neutrality equals climate neutrality due to the time the CO_2 is in the atmosphere before the tree has grown back and assimilated it again (Bright et al., 2012), and the decreased heat accumulation of de-forested areas due to the perturbation of the surface reflectivity, known as the albedo effect (Cherubini et al., 2012). Burning of firewood is also responsible for a large number of other emissions (Ozil et al., 2011). In Norway, burning of firewood is responsible for about 42% of the emissions of fine particles (PM TSP) (SSB, 2011b), 21% of the polycyclic aromatic hydrocarbons (PAH) and 34% of the dioxins (SSB, 2013).

The end-user phase is responsible for the main environmental impact during a woodstove's life cycle; 60% occurs because of the wood burning itself (Solli et al., 2009). In particular the start-up and end phase of the burning process are crucial (Ozil et al., 2011). Emissions depend on the type and condition of woodstove and firewood, but also on the user interaction with the stove (Karlsvik and Oravainen, 2009). The regulation of combustion air to the various parts of the combustion chamber is a main parameter that sets the burn rate and affects the general combustion quality, which is defined by particle emissions. Air supply for most modern stoves still requires manual operation by the end-user and can normally be regulated by two separate handles; one handle for ignition air through the bottom grate and a second handle to regulate the air supply to the primary combustion zone for setting the desired burn rate. The main combustion air controls the overall combustion intensity as given by the instantaneous burn rate at any time in the primary combustion zone. All modern stoves also apply what is called a secondary burnout zone where additional preheated air provides oxygen for gaseous hydrocarbons and particle burnout in the plume slightly above the main combustion zone. Using various canalization solutions, both main combustion air including air for glass flushing as well as the fixed amount of air for the secondary burnout zone, is more or less preheated depending on the stove design. Active regulation of the ignition air is mainly required only when lighting the stove, where it should be fully open during a certain period, normally between 5 to 15 minutes, to support sufficient air until self-sustained combustion has been established, after which it is normally closed. For the remaining burnout and charcoal face, the effect can be set by adjusting the handle for the main combustion air. Many wood stove manufacturers also recommend lighting the stove with the door partly open. Lately recommendations for lighting woodstoves is to light the fire from the top, although this is not yet commonly applied. A 2011 informal survey by consumer interest website www.DinSide.no, found that among 1765 readers of an web-article about how to use a woodstove, only 10% answered that they followed this recommendation.

Based on this knowledge on how stoves behave, there appears to be potential for reducing emissions by designing woodstoves that are likely to improve the way people interact with the woodstove. Therefore, at NTNU a project was initiated to investigate this potential. by improving the design of the user interface. The initiative was a collaboration between SINTEF and the NTNU as part of CenBio, a collaboration between a number of industry partners and universities, aiming at enabling sustainable and cost-efficient bioenergy. The project was done in collaboration with a Norwegian woodstove producer, Jøtul, which contributed both with technical advice, participants to workshops, and the prototype and woodstove for the final testing.

2 METHODS AND RESULTS

The project consisted of four separate phases. First, ethnographic studies on how and why people burn firewood the way they do, which is discussed in section 2.1. Second, the results from the user research phase were translated into a design proposal and subsequent prototype, reported in 2.2. In the next step, a prototype of the design proposal was tested by comparing it with a conventional woodstove in a controlled user test (2.3). Finally, section 2.4 presents the analysis of the results of the testing phase.

2.1. User research

The few available literature studies on how regular users burn firewood (Fisher et al., 2011; Meyer et al., 2008; Scott, 2005) have focused on measuring emissions resulting from behaviour, and to a certain degree on what the users did, but contain limited information about why the users behaved that way. To obtain such data which is essential information for a DfSB process, in early 2012, 17 participants, all regular woodstove users, were recruited in the area around Oslo, Norway. These 11 men and 6 women between 29 and 80 years old included dwellers in apartments, houses and semidetached houses. All participants were visited at home, video recordings were made of the participants firing up the woodstove, and semi-structured interviews addressed why and how they had done this the way they did, as well as other firewood energy and sustainability relate issues. Throughout each interview, participants were asked to maintain the fire in the woodstove, allowing for observation of adjustment of the air vaults and reloading of wood, in cases where this was done. This approach is representative of applied ethnography, where the researcher observes usage of products in its natural setting and by interviews and analysis tries to understand why users behave the way they do. The goal is to understanding how people use products with focus on observing the behaviour in the natural situation, understanding it in the social and cultural context, how the user creates meaning (Blomberg et al., 1993), and understanding the users' implicit or non-verbal needs (Kujala, 2003). It is a technique that can reveal factors affecting the behaviour of the user, which are both conscious and unconscious to the user, and are embedded both within the user and externally (Daae and Boks, 2014).

As expected the ethnographies generated a rich base of information. A summary was made of each interview which formed the basis for creating four personas (Miaskiewicz and Kozar, 2011). Short versions for the more elaborate persona descriptions used for the project are:

- Persona 1. A user who sees burning firewood as a hobby, is knowledgeable but still eager to learn;
- Persona 2. A user who believes he knows everything but does many things wrong;
- Persona 3. A user who enjoys burning firewood but finds it difficult and is insecure;
- Persona 4. A user who does not care and just wants everything to be as easy as possible.

In addition, an overview was made of various recorded elements of behaviours that were not in line with the recommendations for optimal burning, including burning wood that is too moist, use paper and cardboard to start the fire, kindle the fire from the bottom of the wood instead of from the top, not giving flames sufficient air when firing up, reducing the air too much while burning, closing the secondary air while leaving the primary air open, and leaving the door ajar too long.

2.2. Design

The goal for the design phase was to design a woodstove that would make all the personas use it more in line with the recommended way, and would be accepted by all the personas. Idea generation was

fuelled by information about the personas, and various sub-optimal behaviours, and a potential solution space was drawn up. This process was facilitated by an improved version of a recently developed tool, Principles of Behaviour Change, was applied (Boks and Daae, 2012; Zachrisson and Boks, 2012; Zachrisson et al., 2011). The tool, which is based on insights from behavioural psychology, aims to help designers make informed decisions about which design principles to apply when aiming to achieve a desired behaviour change for a target group. The tool has two main parts. The first part consists of two axes describing how much control the user has over the interaction (from where the user is in complete control to where the product is in complete control) and how obtrusive the principle is (from not being noticed in one end to impossible to ignore in the other end). Together these two axes form a solution space landscape, where design ideas or principles can be positioned, according level of control and obtrusiveness. In Figure 1, nine examples are positioned in the landscape to explain how it should be understood.
In the second part of the tool guidelines suggest which parts of the control-obtrusiveness landscape are more likely to have the desired effect on the behaviour of the user based on a number of user characteristics, such as whether the user has habits that should be changed, whether the user wants to behave in the desirable way or not, and how much attention would be required from the user.

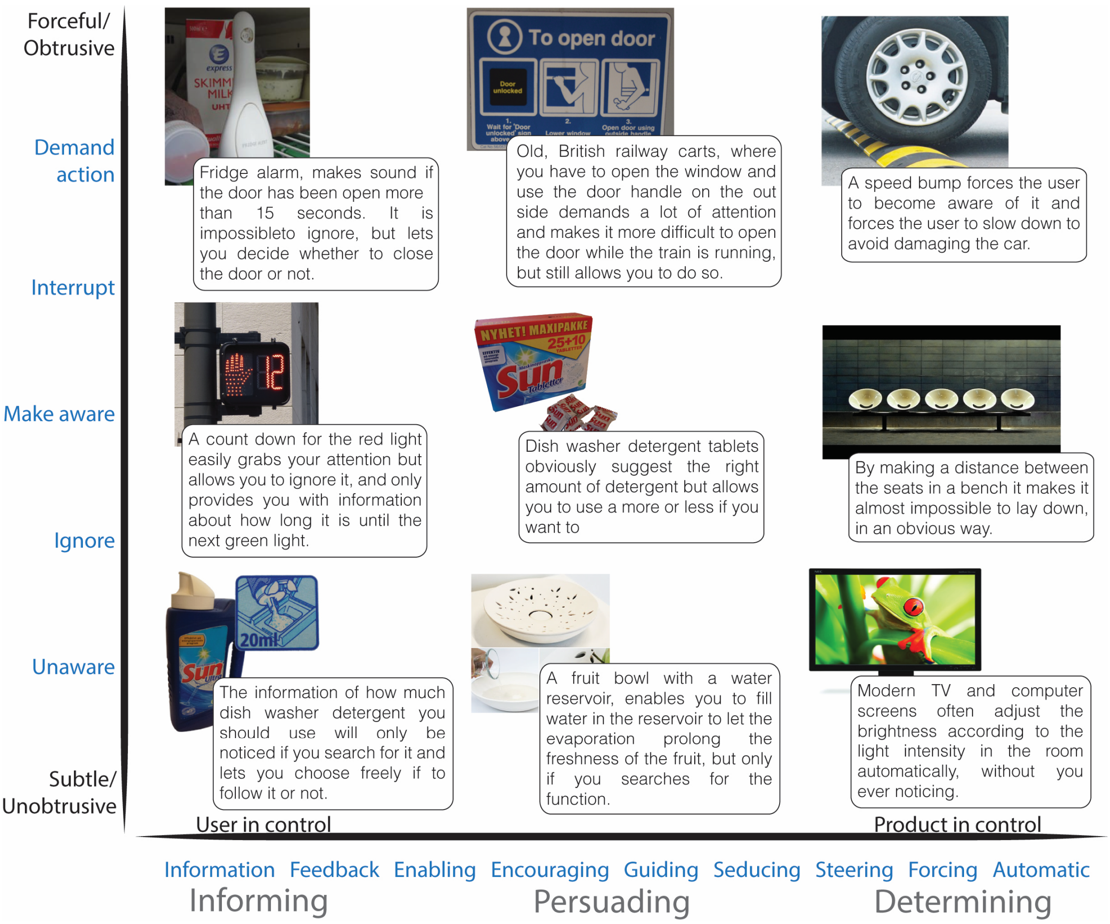

Figure 1. The landscape of Control and Obtrusiveness.

A workshop was organised at Jøtul in May 2012 with seven participants from their product development, marketing and the technical departments. At the start of the workshop, the results from the user research and the personas were presented. The participants were then asked to brainstorm ideas for how to make people use a woodstove more in line with recommended behaviour, particularly targeting the list of sub-optimal behaviours. To keep the challenges simple the personas were given limited emphasis during the idea generation, although it was brought up from time to time to spur the generation of additional ideas. The design workshop generated many, partly overlapping ideas, and a number of distinct ideas were identified. These ideas were positioned in the landscape, according to how much control and attention they demanded from the user, and included for example. With the available ideas almost the entire landscape could be covered.

As suggested in the Principles of Behaviour Change guide, the next step was to identify those areas of the landscape that will potentially result in a desired behaviour change. For each persona, it was decided that solutions high on the obtrusiveness scale would not be acceptable. In addition, solutions on the determining end of the control scale would not fit well to personas 1 and 2, though persona 2 may be susceptive to determining solutions which would be very unobtrusive. For personas 3 and 4, any solution on the control scale may work, as long as these would not be too obtrusive.

Combining results from the previous steps allowed identifying the most suitable ideas which would fit all personas. These were evaluated in collaboration with the technical experts at Jøtul on basis of their technical feasibility. It was decided that the prototype should combine some of the following ideas:

- It should have one lever to make it impossible for the user to close the secondary air but leave the primary air open. With the lever pulled all the way out, both air vaults are completely open; when pushed in a bit, the primary air closes but the secondary air is kept open. The further it is pushed beyond this point, the more the secondary air closes, until it is pushed all the way in and the secondary air is completely closed.
- To help the user understand the different positions of the lever, icons should be provided at the position where 1) both primary and secondary air flow is completely open (to be used during ignition), 2) primary air is closed but secondary air completely open (to be used for rapid burning), and 3) primary air closed and secondary air almost but not completely closed (to be used for slowest possible burning).
- It should have a thermometer on the window at the front of the woodstove, indicating when the air should be adjusted.
- It should have an easily readable, illustrated user manual.

2.3 Testing

To enable evaluation of whether the design concept would actually result in behaviour that is more in line with the recommendations, Jøtul built a prototype of the concept based on one of their existing woodstove models, but instead of changing a conventional woodstove with separate levers for primary and secondary air into the desired combined lever, the prototype was based on the only existing model that actually had a combined lever, and separate the levers on the 'conventional' woodstove instead. This would still allow the evaluation of the effect the combined lever had on the behaviour, but was technically easier to build. The thermometer was positioned on top of the woodstove instead of on the window as the available thermometer registered the temperature directly at the surface and would be too strongly affected when the door was opened (Figure 2). The two woodstoves were transported to the lab of the Department of Energy and Process Engineering at NTNU, where the testing was conducted. The facilities at this lab allowed measurement of the emissions and temperature development when testing the woodstoves. Instead of performing experiments on preheated stoves as specified in the Norwegian standard (NS_3058-2:1994) it was decided to perform the experiments on "cold", room tempered stoves. Cold stoves producers significantly more emissions in the initial start-up phase due to the heat necessary for the heating of the construction itself. Choosing a cold stove as a reference would therefore probably produce larger differences in terms of emissions making it easier to distinguish good and bad stove lightning. Several other deviations from the Norwegian standard were also made, mainly related to fuel type, testing time

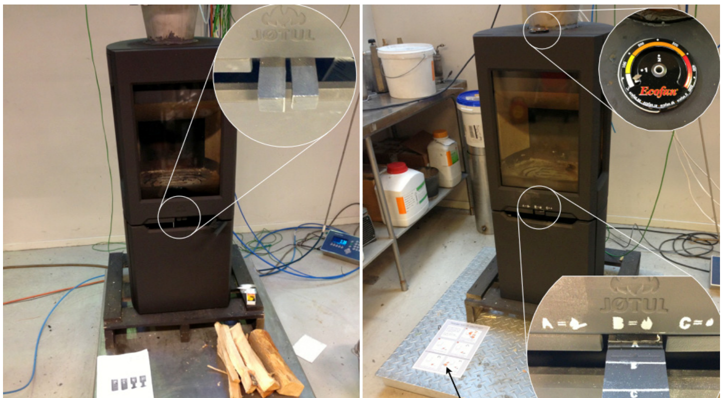

Figure 2: The conventional woodstove to the left and the prototype to the right.

and fuel charge, to make the context more similar to what regular users are customed to.. Also, since most particle emissions are produced early in the batch burning period, each experiment was run until 80% of initial mass had been consumed.

In August 2013, 20 participants between 30 and 81 years old, all regular woodstove users, were recruited in the Trondheim area. In each test, a participant came to the lab, answered a few questions about their woodstove experience and burning habits, and lighted a fire in one of the woodstoves. No explanations were given of how to operate the woodstove, but before lighting the fire the participants were asked to explain what they believed the purpose was of the different parts of the woodstove. During the burning process, the test leader paid attention to what the participant did, but without commenting on it. After the test, the participants of the prototype were asked specifically about whether they had noticed (and used) the steps on the air vault lever, and what they thought of it. To enable a direct comparison between tests, the woodstoves had to be cold and empty of ash before each test. Thus, it was only possible to conduct one test in each woodstove per day, alternating daily which woodstove was used first and last. For every test, the participants were provided with three firelighters, a matchbox and 2.2 kg (+/- 0.02 kg) of wood in some smaller and some larger logs, with moisture varying between 17.5% and 20.9%. Some participants needed more than the three firelighters, and were given additional ones. The testing lasted until 20% of the mass of the wood was left in the woodstove. Measurements were made every minute of the emissions of CO_2, CO, O_2, and NO_x. In addition, the weight of the remaining wood and temperature development in the smoke was recorded, and the total fine particle (PM) emissions were measured.

2.4. Analysis

None of the participants that used the prototype consulted the user manual and the few who noticed the thermometer, thought it was part of the measuring instruments and not something they should pay attention to. However, half of the participants using the prototype noticed the icons and letters before or during the beginning of the burning process, and they all used it actively both by adjusting the air according to the icons and by naming the letters when talking about what they were doing. Among the participants who did not notice the icons, four out of five were very enthusiastic about them when they were asked about them after the test. They also said they believed they would have interacted differently with the woodstove if they had noticed them before the test.

The way the participants used the woodstoves was analysed to evaluate to what extent their behaviour was in line with recommendations. Particular attention was paid to whether the participants had lighted the fire from the top, closed the primary air when it burned properly, adjusted the secondary air and achieved a successful secondary burning. These criteria, together with other observations and the general evaluation of what the participants had done, formed the basis for rating their behaviour on a scale from “not at all” in line with recommended behaviour to “identical” (see Table 1). Based on this evaluation, it is apparent that the five participants who noticed the icons behaved identical or quite in line with the recommendations. They also closed the primary air, adjusted the secondary air and achieved good secondary burning.

Table 1. The number of participants performing particular actions and how much they were in line with the recommended behaviour.

The conventional woodstove		
Lighted the fire "from the top"	Yes	4
	No	6
Closed primary air after it burned properly	Yes	2
	No	8
Adjusted secondary air	Yes	4
	No	6
Good secondary burning	Yes	6
	No	4

How similar was the behaviour to the "ideal"					
Similarity with recommended (1= not at all, 5 = identical)	1	2	3	4	5
No. of tests	3	4	1	2	0

The prototype		Noticed	Did
Lighted the fire "from the top"	Yes	3	2
	No	2	3
Closed primary air after it burned properly	Yes	5	1
	No	0	4
Adjusted secondary air	Yes	5	1
	No	0	4
Good secondary burning	Yes	5	3
	No	0	2

How similar was the behaviour to the "ideal"					
Similarity with recommended (1= not at all, 5 = identical)	1	2	3	4	5
Tests not noticing the icons	2	1	2	0	0
Tests noticing the icons	0	0	0	3	2

The measured emissions showed substantial variations in all categories. Due to the small sample size, none of the differences are significant (Table 2) which is not surprising; significance would require a very large effect. To test the statistical power of the results, assuming a normal distribution, a two sample t-test for mean difference identified that there would be 80% probability of significant results for PM with 91 participants in each group and for CO with 194 participants. There are however clear indications from the testing results that suggest that the prototype resulted in better burning processes than the conventional woodstove. After each test, the ash was removed from the woodstoves, but no other cleaning was done. Before the testing, both woodstoves were almost unused and consequentially had completely clean glass at the sides and on the door. During the testing, the glass surfaces on the conventional woodstove gradually got increasingly opaque, whereas glass on the prototype stayed clean (Figure 3).

Table 2. Comparing the measured emissions. W = the rank sum, z = the unit of normal distribution and p = the significance level.

	Conventional woodstove			
	PM g/kg	CO at 13 O_2 vol%	NO_x at 13 O_2 vol%	CO_2 vol%
Prototype	w=190 z=-0.245 p=0.8065	w=136 z=1.004 p=0.3156	w=190 z=-0.572 p=0.5675	w=190 z=-0.245 p=0.8065
Only participants who noticed the icons	w=105 z=0.333 p=0.7389	w=78 z=1.368 p=0.1712	w=105 z=-0.734 p=0.4629	w=105 z=-0.067 p=0.9468

Figure 3. Soot on glass door after the testing. The conventional woodstove to the left and the prototype to the right.

When considering the burning intensity of the wood and the emissions of particles, it is also apparent that all measurements from participants who noticed the icons are centred around the same area, whilst the other measurements are much more spread out (Figure 4). This observation is also supported by the smaller standard deviation for the participants that noticed the icons, for almost all the emissions.

3 DISCUSSION

The results from the testing suggest support for the hypothesis that the design of woodstoves can make people use them more in line with the recommendations and potentially reduce the emissions. Given the small sample and the number of non-controlled behaviours that affect the emissions and contribute to the spread in the measurements, a significant result would almost be remarkable, and there is a clear effect, even if it is non-significant. For instance comparing the average PM emissions, the participants who noticed the icons on the prototype emit only 65% as much as the conventional oven. Assuming that this result did not occur by chance but is representative for the population and this design was applied to all ovens in Norway, 1/6th of the PM emissions in Norway would be eliminated. If this is true, the effect of the relatively small adjustments is impressive. The results of the test suggest therefore that it may be worth conducting a large scale experiment to find out if the results are representative for the population. Also, when analysing both the ways the different participants lighted the fire and the emissions resulting from the burning process has a very strong effect on the results.

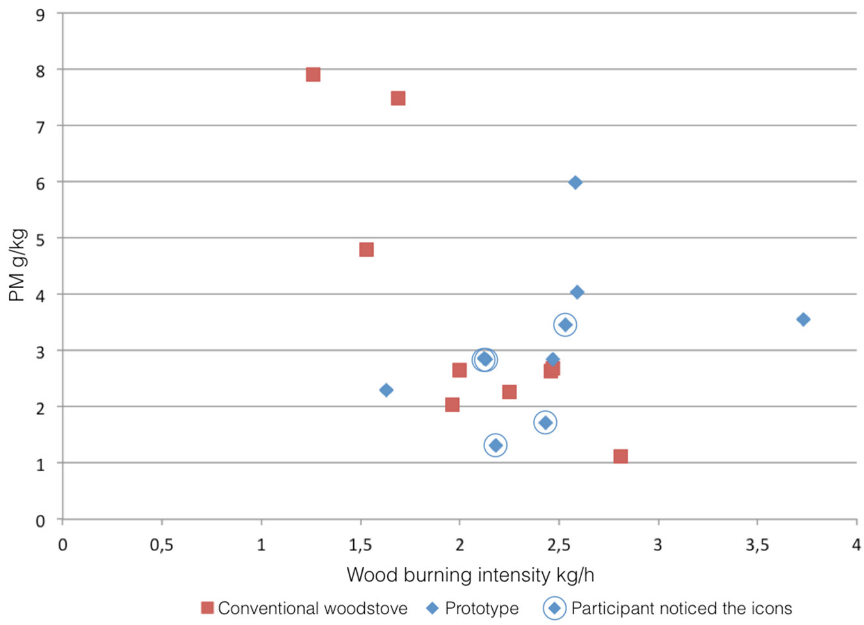

Figure 4. Plot of particle emissions (g/kg) and wood burning intensity (kg/h)

Participants who had problems with getting the fire to burn properly and spent a long time before they achieved a proper secondary burning process, also, with one exception, had the highest PM/kg emissions, although two of them were among the participants who noticed the icons and behaved more or less according to the recommendations. This result suggests a benefit in exploring further how the design of woodstoves may be improved and to do further testing without variations in the way users light the fire. The primary function of the combined lever was to simplify the air adjustment and avoid closing the wrong air valve. Possibly the thermometer could have simplified this even further, but as none of the participants noticed this, the test is unable to evaluate this aspect. Further simplification of the adjustment of the air valves, and possibly other aspects of the interaction with the woodstove, is undoubtedly possible and potentially valuable. The icons added to this effect by providing the users basic information about the different positions of the lever. The test shows that the most participants were both responsive and enthusiastic about this type of support. This effect may be enhanced further by for example having a longer movement of the lever, facilitating small adjustments to the secondary air, and possibly improve use of icons to better communicate the usefulness of the area between the two extremes for the secondary air. The fact that only half of the participants that used the prototype noticed the icons, the thermometer and the simplified user manual, is in line with the known challenges connected to affecting a habitual behaviour (Klöckner and Matthies, 2004; Verplanken and Wood, 2006), which is likely to be the case for regular woodstove users. In the context of the woodstove, this presents a challenge, as a design that would be obtrusive enough to break the habits of the users is unlikely to be accepted by the users. Thus, the way the behaviour changing aspects of a new woodstove are presented should be further researched. The lack of attention given to the user manual may also result from the lack of attention user manuals often are given. The thermometer was interpreted as one of the many measuring tools attached to the woodstove, and thus may have had more effect if applied in a non-lab setting.

Reflecting on the research methodology, the use of Principles of Behaviour Change to evaluate the likelihood of the ideas resulting in the desired behaviour change and being accepted by the users, may have had limitations. First of all, the positioning of the ideas in the landscape is difficult, particularly because the position may depend strongly on how the principle is applied, not only on the type of principle. The results of the analysis only indicate that particular types of principles have the potential to result in the desired behaviour or are likely to be accepted by the user. There may also be several other aspects of the design of a product that may affect the potential success of the design. Nevertheless, the tool does has provided useful indications and does provide additional understanding of how the product affects the user, in addition to the exclusion of directly unsuitable ideas.

3.1. Limitations

Social desirability or prestige response bias (Courage and Baxter, 2005) may have affected the results of the applied ethnography conducted in the user research phase. In recent years, Norwegian newspapers and magazines have frequently featured articles with descriptions of how one should use modern woodstoves. Some of the participants may have adjusted their behaviour out of embarrassment about their incompetence, which would have resulted in social desirability. The prototype testing had a similar risk of social desirability. In addition, the behaviour of the participants may have been affected by the unfamiliar nature of the surroundings of the test. There is also a risk of prestige response bias, in particular when participants were asked to comment on the icons on the prototype; they may have understood that these were central in the testing and possibly something the test leader was responsible for. The nature of the variations in the measurements of the emissions also contains a number of uncertainties, as there were some variables that could not be controlled. Most importantly, the emissions depend on several aspects of the participants' behaviour, such as how many firelighters they use, how tightly the pack the wood, at what time they reduced the air, etc., which could not be controlled as the intention was to investigate how people naturally would interact with the woodstoves. A few limitations were made to the participants' behaviour, as they were given a controlled amount of wood, firelighters and matches. Several of the participants were used to using large amounts of small wood or paper, but allowing the use of this would dramatically have increased the uncertainties. The variations in other aspects of the participants' behaviour are likely to be the key reason why there is less significant reduction in the emissions from the participants who adjusted the air according to the recommendations.

4 CONCLUSION

This paper is likely one of the first examples reported in literature that documents a complete user centred, Design for Sustainable Behaviour process, from the initial user research, through the design phase to the building and testing of a prototype. The purpose was to investigate whether an alternative design of a woodstove, informed by principles of design for behaviour change, will make people interact with it in a way that is more in line with the recommended behaviour, and if this would result in reduced emissions. The initial user research resulted in the creation of four personas, which were used to inform the new design. The most promising and feasible design was selected through a combination of consulting technical personnel at Jøtul and the application of a tool called Principles of Behaviour Change. The resulting design was translated into a prototype, which was tested together with a conventional woodstove, in a lab with regular woodstove users. The reductions in the emissions resulting from the test are relatively large but are all non-significant. However, the prototype did result in behaviours that are more in line with recommended behaviour. The non-significant emission results are likely to be a result of the small sample size in the testing, and could benefit from a larger scale testing of the prototype for confirmation or rejection. If such a test should be conducted, it would be interesting to focus on later stages of the burning process, or in other ways remove the variation in how the participants lighted the fire, as this had a large effect and made it difficult to measure the effect of the new design.

The study shows that there is a potential for improving the way people adjust the air to woodstoves by improving the design and that it is important to also target how they ignite the wood. The description of the design process and the relatively positive results from the testing of the prototype, may contribute to improvement of DfSB processes and attention to the potential environmental benefit from affecting behaviour through product design. The study also provides potentially valuable information to the design of woodstoves, by identifying the benefit of simplifying the air adjustment with a combined lever and guiding the behaviour of the users with icons for the right lever positions.

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