THE SONIC CARPET: REAL-TIME FEEDBACK OF ENERGY CONSUMPTION AND EMISSION DATA THROUGH SONIC INTERACTION DESIGN

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ABSTRACT

As buildings become increasingly automated and energy efficient, the relative impact of occupants on the overall building carbon footprint is expected to increase. Research shows that by changing occupant behaviour energy savings between 5 and 15 % could be achieved. A commonly used device for energy-related behaviour change is the smart meter, a visual-based interface which provides users with data about energy consumption and emissions of their household. This paper approaches the problem from a Sonic Interaction Design point of view, with the aim of developing an alternative, sound-based design to provide feedback about some of the data usually accessed through smart meters. In this work, we experimented with sonic augmentation of a common household object, a door mat, in order to provide a non-intrusive everyday sonic interaction. The prototype that we built is an energy-aware sonic carpet that provides real-time feedback on home electricity consumption and emissions through sound. An experiment has been designed to evaluate the prototype from a user experience perspective, and to assess how users understand the chosen sonifications.

1. INTRODUCTION

Smart Home technologies are a major focus of sustainability research in engineering, as the residential sector accounts for 25 % of primary energy consumption in western countries [1]. Many proposed approaches involve the introduction of new technologies for monitoring and automating energy-related aspects of buildings. A common way to achieve energy savings is providing feedback and incentives to reduce consumption, with technologies such as smart energy meters, which are visual-based interfaces that provide real-time and historical feedback related to energy. Present and future investment in smart metering technology has been estimated at 51 billion Euros, with the potential for savings ranging from 14 billion to 67 billion Euros [2]. Despite these estimations and the huge amount of investments, the real-world studies conducted on the effectiveness of smart meters do not present clear conclusions on the amount of savings that have been achieved. In fact, most of the literature about the subject suggests that conventional methods of personal energy monitoring systems achieve modest results on long-term behaviour change for energy efficiency. A possible problem leading to the ineffectiveness of smart meters might be their design and their way of providing feedback, which is entirely based on visual communication (mainly graphs, diagrams) and might not be engaging enough or appropriate for all users [3, 4]. For this reason, it is worth exploring alternative possibilities of interaction with this data for the household environment. This paper specifically proposes a sound-based interface for the household environment to provide energy information. Our prototype is an Energy-Aware Sonic Carpet, which provides a real-time sonification of the current state of the household electricity consumption and emissions when stepping on it.

The content of the paper is organized as follows. After summarising relevant literature in Section 2, we describe the design of the developed prototype in terms of physical interface, sonification variables and sound design in Section 4. Section 5 describes the design of the user evaluation test, and results are analysed in Section 6. Finally, discussion and conclusions are outlined in Section 7 and 8.

2. BACKGROUND AND RELATED WORK

There is general consensus in the energy efficiency community on the fact that occupants behaviour is a major driver of energy consumption in household environments [5, 6, 7, 8]. For example, occupant behaviour is commonly identified as one of the main causes of Energy Performance Gap (EPG), the difference between consumption of a building that have been predicted by a simulation and the actual measured ones. Even if, as discussed by Mahdavi et al. (2021) [5], the extent to which behaviour contribute to the EPG is not clear in the literature, it is nevertheless a fact that occupants have a role in the building's operations, which they can influence passively or actively.

A lot of research is focused on the decreasing energy consumption by providing feedback to the household occupants about their energy usage. Depending on the users, feedback interfaces can range from visual displays in dedicated devices [9, 10, 11], smartphone apps [12] to digital games based on real-time sensor data [13]. The data available to the users is in general real-time information about energy consumption with different levels of precision and possibilities for users to navigate the data. Some systems allow to represent the data in different ways, as the same energy consumption quantity can be represented in scientific terms, typically in kWh, but can also be shown as price or CO_2 equivalent (CO_2e) emissions. Different representations can be preferred by different users, depending on individual values and behavioural determinants. A common way of providing feedback about energy

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consumption is through smart meters. Even though an increasing amount of literature is dedicated to these devices, there is no precise definitions of what counts as a smart meter. Nevertheless, there is a general agreement that it is a device able to measure and store energy consumption data at specific time intervals and enable two-way communication between supplier and consumer for Automated Meter Management [14]. Potential energy savings due to the deployment of smart meters have been estimated to 5-15% [15, 16]. These figures are however highly variable depending on modes of feedback delivery and the overall context. Qualitative data shows that users are usually interested in engaging with this kind of technology [17] and become more aware of their consumption, modifying their behaviour at least in the short term.

The topic of energy awareness has been approached from multiple sides in Human-Computer Interaction (HCI). Though design research unconventional interfaces for energy monitoring are explored. These interfaces can range from built and tested objects, to new methods of digital visualization, to speculative experiments and design fiction exercises. Pierce and Paulos (2012) [18] reviewed some experiments and emerging trends in energy-related HCI. All of the contributions analysed by the authors are based on a novel design artifact, with the main focuses of providing Energy Feedback - generally by digital visualization - and encouraging broader energy awareness and conservation behaviour. Besides papers focused on screen-based visualizations [19, 20, 21, 22, 23], other visual techniques to provide energy feedback include the use of lighting and physical objects, with variable degree of complexity and affordances. Some of the analysed contribution involve subliminal information [24], affordance-based persuasion [25] or gamification [26] approaches. Some examples of alternative visualization techniques include the Power-Aware Cord [27], the Energy-Aware Clock [19], lamps that change their color based on energy consumption [28] and audiovisual installations [29].

In the last few decades, a number of Auditory Display studies have focused their attention to the domain of environmental data. Ambient sonifications have been used multiple times in environmental applications, such as water toxicity [30], real-time pollution data in urban environment from complex sensor networks [31]. Energy has been an area for invenstigation for sonification, with multiple experiments focusing on energy awareness and household applications. Fickert et al. (2006) [32] presented *SonEnvir*, a sonification software, and its application to complex oscillating behavior of electrical power systems. The authors experimented with sonification methods to find disturbances in the power grid. Their research shows the potential of sonification to highlight physical qualities of electricity flows in a more evident manner with respect to visualization techniques. Power grid data has been approached also by Cowden and Dosiek (2018) [33], who sonified frequencies and voltage variations in a grid, suggesting also a design for a real-time grid sonification device. Household consumption has been approached by Hammerschmidt et al. (2013) [34], who propose a system to sonify water consumption in the shower. In their experiment they use blended sonification, combining ambient sounds with synthesized ones, to give personalized feedback about the cumulative energy consumption in the shower time. Gro-Vogt et al. (2018) [35] propose a sonification of the electric power consumption of an institute's kitchen. Based on the Parthy's investigation of reverberation as a carrier of ambient information (2004) [36], in this project the reverberation of a room is changed depending on the difference between the current consumption and a weekly baseline. Another approach to household energy data is *Powerchord*, a project by Lockton et al. (2016) [37]. It is a system for energy feedback with real-time sonification for user behavioral change. The authors have conducted multiple workshops with residents which led to different sonfication ideas. Working on the project, the authors developed *Bird-Wattching*, the sonification of power consumption in the kitchen using bird sounds, outlined in [38].

3. MOTIVATION

Our literature review highlighted a number of issues with current methods for providing information about energy consumption. To tackle some of the current problems with energy feedback technology, we developed a simple feedback object that could seamlessly integrate in the home environment and that would be an alternative display of some of the information normally provided by the smart meter. We wanted to explore the idea of *augmenting* with sound normal household objects, instead of introducing a new object. This would allow us to make use in the design of the already established familiarity with the object and modes of interaction. The energy-aware carpet is thought of as a flexible, non-intrusive object that can be easily embedded in the habits of users. The carpet can be easily ”checked” when users prefer, and it is silent for the remaining time, encouraging *sporadic interactions* [39]. Another assumption behind the decision of working with a common household object like a carpet is that the interaction with it can easily become part of the user's habits and routines, and therefore require lower attentional demand and implicitly communicate information. Several motivations guided the decision of using a carpet as an interface. Rugs are flexible objects that can have multiple uses and possible shapes, and they can be positioned in different places in the house. The affordances of a carpet can be connected to routines - like usage of a doormat or a bathroom rug - or more complex interaction, for example in the case of a living room or bedroom carpet that might be used also for shared activities and playful interactions. A carpet has a visual and a tactile component, which can be integrated in the feedback structure when designing sonic interactions. Moreover, a carpet provides interesting possibilities for playful behaviour, it integrates within the home environment and it provides a rich palette of possible motion interactions. Most importantly, the carpet allows the user to hear the sonic feedback only when stepping on it, therefore avoiding any unwanted intrusiveness. For this particular prototype we chose to use a doormat-type carpet. As the user walks in and out of the house, they receive sonic feedback about the state of energy consumption as they step on their doormat.

4. DESIGN

This section describes the realization of the prototype of a sonic interaction object that has been developed for this paper. The object is an Energy-Aware Sonic Carpet, which produces sounds when stepping on it. The sound output consists of a real-time sonification of different information about the energy consumption, emissions and sources of energy production in the household.

4.1. Physical prototyping

The starting point for the physical prototype is a basic doormat (dimensions 40x60 cm), shown in Figure 2, made of a rough fiber: a relatively simple object with a clear defined use. To obtain data about people stepping on the carpet, we used six Force Sensitive Resistors, which have been positioned at equal distance on a wooden surface, as in Figure 1.

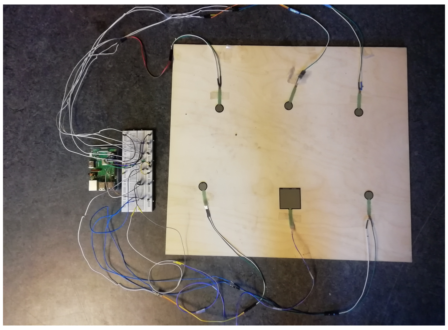

Figure 1: Prototyping platform with Force Sensitive Resistors

The doormat has been spray-painted with icons corresponding to different energy sources, indicating the position of the six pressure sensors. The sensors are connected to a Raspberry Pi 4B+ microcontroller.

Figure 2: Physical carpet interface

Sound can be produced by pressing on the pressure sensors. More than one sensor can be pressed simultaneously. Given the carpet's dimensions, an adult person can easily potentially step on 4 sensors simultaneously: two per foot.

Each sensor provides real-time auditory feedback about two energy data aspects. The top row of sensors provide feedback about consumption. the bottom row about emissions. Additionally, each sensor provides information about contribution of each energy source (wind, hydro, nuclear, geothermal, gas, solar) at a particular moment in time.

The software is coded in Python and Pure Data. Python has been used to access the sensor data from the Raspberry Pi digital input pins, and to perform a simulation of real-time energy consumption. Pure Data has been used for sound design. The code used for the model is available in open-source at https://github.com/vincenzomadaghiele/investigating-real-time.

4.2. Variables to be sonified

The energy variables chosen for the final prototype are **Real-time consumption**, **Real-time emissions** and **Grid split**, which is the amount of energy coming from different source of electricity at any given moment. These variables have been used to develop two different sonification modes for the carpet, one representing consumption and emissions, and another one representing energy sources. One advantage of sonifying this type of real-time energy data is that it does not change too quickly, unless appliances are turn on or off exactly when the carpet is used, so users have the possibility to explore the interface and concentrate on the sounds for relatively long amounts of time while the sonic output remains relatively stable.

4.3. Sound design

The sound design method utilises Parameter Mapping Sonification:

- **Consumption:** the sonification of consumption data uses the Fourier Resynthesis technique to produce sounds, inspired by example I03.resynthesis.pd in Pure Data. The amount of real-time energy consumption in kWh is mapped to the amount of frequency bands whose gain is not zero in the spectrum, after being properly scaled. The higher the consumption, the higher the number of high-pitched frequency bands activated. Spectral components have been chosen as a sonification parameter, as frequency has proved successful in a number of sonification experiments related to physical quantities [40]. The frequencies are in the range 520 - 5107 Hz.
- **Emissions:** The value of real-time emissions has been sonified by using frequency modulation with noise. The sound from the Fourier Resynthesis of the first sonification is frequency-modulated by low-pass filtered white noise. The amount of emission data influences the amplitude of the modulation noise, the cut-off frequency of the low-pass filter and the amount of noise-modulated signal that is mixed with the original one. This sonification has been approached as a metaphor [41], exploiting the cultural association between noise and pollution.
- **Grid split:** The sonification of Grid Split has been realized using a *bell* sound with a different pitch for each of the energy sources, adapted from example D07.additive.pd in Pure Data. In this sonification, the percentage of energy coming from each source has been mapped to the duration in time of the bell sound, and the six different sources are mapped to six different fundamental frequencies. The result is a series of *earcons* where pitch represents the energy source and the duration represents the percentage of that source. This choice is motivated by the fact that single earcons can be perceived even when in conjunction with continuous sonifications such as those described above, and by the fact that pitch and duration can easily express discrete information quantities [42]. The six different center frequencies that have been used are part of the A minor pentatonic scale. The specific frequencies of the pitches used to identify each energy source are 440.00, 523.25, 587.33, 659.26, 783.99, 880.00 Hz. The duration mapping ranges from 0.5 to 3 seconds.

We envisioned an interface that should seamlessly represent multiple sonification variables at the same time. For this reason, we chose mappings that could be clearly separable between each other. In the case of consumption and emissions the distinction is based on timbre; the higher the frequency range, the higher the consumption, the more noise in the mix, the higher the emissions. For the grid split sonification the two variables are represented together by the pitch and the duration of each sound; pitch represents the energy source (wind, solar, etc.) while the duration represents the amount of energy coming from the source. The amount of foot pressure detected by the force-sensitive resistors placed under the carpet is also mapped to a low-pass filter in all sonifications. This was done to increase the responsiveness of the interface to user input and obtain a more organic interaction feedback.

5. METHODS

This section presents the evaluation procedure that has been carried out for this prototype. This is a pilot study part of a longer process of design and results will be used to modify and improve the design of such an object in further iterations.

5.1. Test design

The study that has been developed to evaluate the Energy-Aware Sonic Carpet has two main goals:

- **Intelligibility of sounds:** determining whether the participants are able to correctly identify the information corresponding to each of the sounds. This aspect has been tested using an *Identification* task [42];
- **User experience:** understanding which aspects of the interface is engaging and interesting to interact with, and which ones could be changed and how. This aspect has been addressed with a survey which includes open questions as well as ratings according to five criteria selected among the ones proposed in the User Experience Questionnaire (UEQ) Handbook (2019) [43] based on their relevance to this project;

Identification tasks "provide a measure of accuracy for determining whether participants can recognize and label sound stimuli" [42]. They are the simplest way to determine whether participants can associate sounds and information. To ensure comparability of results, sound stimuli for the Identification task have been sampled at three levels from their continuous mappings. The levels are described in the survey as *low*, *medium* and *high*, and correspond to the respective levels of consumption, emissions or amount of energy from a particular source. Before each of the listening tasks, participants listen to the sounds corresponding to the three levels to be familiar with them before starting the Identification Task [1].

Two different tests - an online listening test and an in person user-experience test - have been developed to evaluate sound intelligibility and user experience separately. The online listening test was organized in this way:

1. **Subject background information:** participants write their age, gender and musical background;
2. **Listening test I - Consumption and emissions:** after listening to sound examples corresponding to *low*, *medium* and *high* consumption and emissions separately, participants are asked to identify the correct amount of consumption and emissions in six different sound stimuli. After the listening test participants are asked to rate the sound on five different perceptual scales and freely comment about them;
3. **Listening test II - Grid split:** after listening to sound examples of the bell sounds corresponding to each energy source and to the bell sound duration corresponding to *low*, *medium* and *high*, participants are asked to identify the energy source and the amount of consumption in six different sound stimuli and freely comment about them;

The user experience test, carried out in presence, was structured in this way:

1. **Subject background information:** after signing a consent form, participants write their age, gender and musical background;
2. **Getting familiar with the sounds:** after listening to some sound examples, participants perform an identification task (similar to the one described for the online test) with the objective of getting familiar with the sounds before testing the interface;
3. **Test with the interface:** participants evaluate the carpet interface in the two alternative configurations (Consumption+Emissions and Grid Split) separately. Differently from the listening tests, sounds are in this case emitted as the user steps on the carpet. Participants experience the carpet with three sets of different values (these sets of values are randomised between participants);
4. **Open questions:** participants answer to some basic open written questions about their experience with the object and their opinions about it;

5.2. Participants

The listening tests was carried out using the online platform Psytoolikt [44, 45] in connection with the Prolific platform for recruiting participants. This involved 41 participants. The test lasted approximately 10 minutes. The 41 participants had an age between 19 and 57, with an average age of 27. 21 participants identify as male and 20 as female. 7 participants have no sound or music background, 18 participants have basic knowledge, 14 described as intermediate, and 2 participants self-described as having advanced musical knowledge.

The user experience test was carried out in person, and it involved 7 participants (2 female, 5 male; aged between 27 and 49, average age: 37). All of the participants besides one stated that they had musical or sound education varying from intermediate to professional level. Tests were carried out in the Media Production Studio within the Department of Media Technology and Interaction Design at KTH.

6. RESULTS

6.1. Online identification tasks

Results of the Identification task are represented in terms of Accuracy scores. The accuracy of each category of sound stimuli is the percentage of times such stimuli have been correctly identified by participants.

The results of Listening test I are reported in Figure 3.

The results of this task were all well above 57%, with the Emissions sonification reaching 79.67% of accuracy on *low* sounds and 78.05% on the *high* sounds, and performing quite worse on the *medium* sounds. The results of the Consumption

[1] The sounds that have been used for the test are available here: https://github.com/vincenzomadaghiele/investigating-real-time/tree/main/test

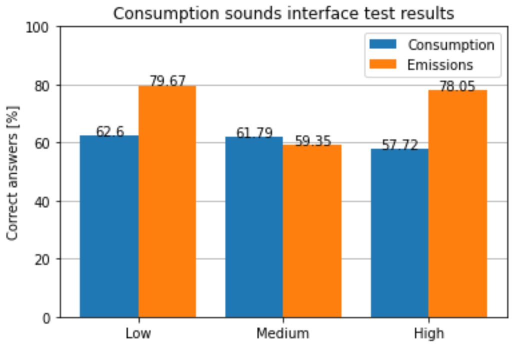

Figure 3: Listening test II - results of the identification task on consumption and emissions

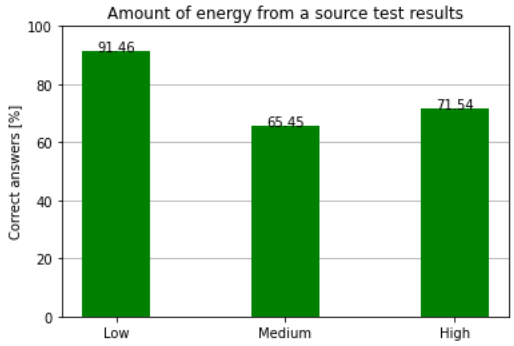

Figure 5: Listening test II - results of the identification task on amount of energy from each source (duration mapping)

sonfication are more homogeneous among the three levels, reaching respectively 62.6%, 61.79% and 57.72% of accuracy, on *low*, *medium* and *high*; overall a lower accuracy with respect to Emissions. The average accuracy obtained by the Consumption sonification was 60.7%, while the accuracy obtained by Emissions sounds was 72.35%. The results of Listening test II are reported in Figures 3 and 5.

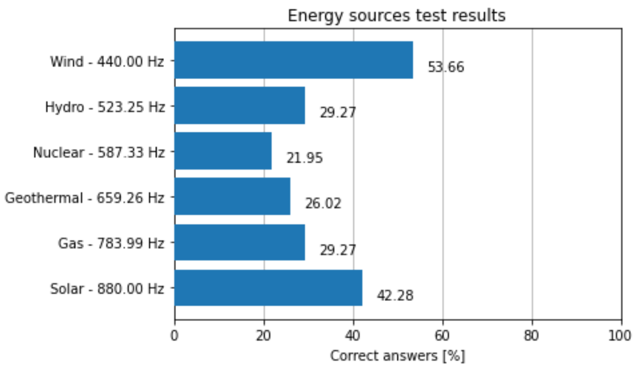

Figure 4: Listening test II - results of the identification task on energy sources

The results of the energy source recognition mapped to pitch yield a quite evident trend: frequencies at the extreme of the proposed scale are much more easily recognized with respect to the ones in between. Even in the extremes, accuracy reaches in this case a maximum of 53.66% for the Wind sound. Overall, the average accuracy obtained by this sonification was 33.74%. The lower accuracy could be due to a difficulty in remembering which pitch corresponds to which energy source given the relatively high number of sources considered - 6.

The results obtained by the duration mapping for the amount of energy corresponding to each source are quite positive. Duration mapping confirmed to be quite successful at representing amounts of data, and especially the duration corresponding to *low* amount of energy was very easily recognized, obtaining 91.46% of accuracy. The durations corresponding to *medium* and *high* were less easily recognized and at times confused among each other, and obtained lower scores, respectively of 65.45% and 71.54%. The average accuracy obtained by this sonification was 76.15%.

6.2. Online ratings of sounds

After the listening test, participants to the online survey have been asked to rate the sounds on a scale from 1 to 7 according to five criteria relevant to this project selected among the ones proposed in the User Experience Questionnaire (UEQ) Handbook (2019) [43]. The selected criteria are *Annoying/Enjoyable*, *Unpleasant/Pleasant*, *Clear/Confusing*, *Understandable/Not understandable* and *Easy to learn/Difficult to learn*. The average responses are shown in Figure 6.

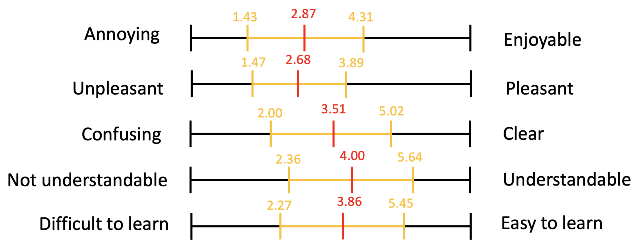

Figure 6: Sound preference ratings

We obtained positive results for understandability and learnability. While, on average, results show that sounds need to be improved in terms of their pleasantness and annoyance. However, it should be considered that the results reported in Figure 6 are averages and, as confirmed by the following comments, personal opinions about sounds can be quite diverse. For example, a participant commented “I think with more practice to me these sounds would be very easy to understand” and another one stated “I think with more of a training period I could get more accurate with my guessing”. On the other hand a third participant commented “It was harder to differentiate between the consumption sounds than between the emissions noise levels”. A less positive response was recorded on the participants’ enjoyment of the sounds themselves, which are not considered particularly pleasant or enjoyable. Despite these averaged results, personal opinions of participants were very different, especially on the first two criteria, with some participants finding the sounds more pleasant and enjoyable and some others rating the opposite. Some comments on the sounds include “Could be more of a distinction between high/low consumption.

Maybe more of an impact on high frequencies" and "Sounded like I was in a science fiction movie. A bit tense sounds, maybe stressful".

6.3. User-experience test

The user experience test was carried out in person. Participants were asked to perform a similar identification task to the one presented in Section 6.1, first without the carpet interface, in order to get familiar to the sounds, and then with sounds actually being the result of stepping of the carpet.

During this test, we asked participants to answer open questions about their experience with the sounds and the interface:

1. *Can you describe how this experience made you feel?*
2. *What aspect do you like the most and why?*
3. *What aspect do you like the least and why?*
4. *How would you change the aspect that you like the least?*
5. *Can you imagine using an auditory augmented carpet in your home? If yes, what would it look like and what would it sound like?*

Participants' opinions were very diverse. Despite being very general, the first question provided a good range of diverse responses, some people reporting to be "curious" (P7), "interested" (P6) and others stating that they were feeling "Confused" (P1) or that the experience was "a bit frustrating" (P2). When asked which was their favourite aspect of the experience, some participants referred to the physical interaction with the carpet emitting sounds (P5 and P7), others to the idea of having access to consumption and emission data through sounds (P2, P3, P4 and P6). In particular, P2 stated "I like imagining how this could fit in my house, what appliances it would work with etc. I think this is great that it brings up these thoughts!". When asked about their least favourite aspects, some participants said that it was the uncertainty of some of the feedback, others criticized the sound of the bells, referring to them as "horrible" (P5) and difficult to understand (P3). A particularly interesting feedback came from P2, an interaction designer, which pointed out: "The interaction with feet why? I dont feel like its a natural mapping". Most of the answers to question 4 were suggestions on how to improve the sounds, proposing "bird chirping" (P5), changing "timbre" (P6) and "add more sonic differences" (P7). When asked if they would imagine to have an auditory carpet in their home, five participants out of seven answered positively. Some participants described how they would use it, for example "would be a good check that the lights are off and the stove is off etc." (P3) and "Possibly positioned at an entrance to a room or apartment so I could monitor as people come and go" (P4). P2 commented that they would use it if "it would fit the aesthetics of my home and the actions I normally do at home" (P2), while P7 interestingly observed "Im not sure it would matter to me that it is connected to data".

7. DISCUSSION

Overall the chosen sonifications produced quite mixed results. Even though their interpretability was satisfactory, as confirmed by the listening test and the sound ratings, the chosen sounds were not considered very pleasant by the participants. Considering the average accuracy metric, the most effective sound to data mapping among the used ones was the duration mapping used for the amount of energy coming from each source. The Emissions mapping to noise obtained relatively good results, followed by Consumption. The pitch mapping used for the different energy sources in Grid Split was not successful, probably because of the high number of different stimuli, which were difficult to remember correctly by participants. It should also be noted that achieving very high accuracy in terms of interpretation was not expected in this work. Our hypothesis is that accuracy of interpretation would rise with time, as users would grow accustomed to the sonic interaction with everyday use.

From the user experience point of view, the test provided insight into the aspects participants were mostly interested in - such as gaining information about consumption and having a fun responsive interaction - and the ones they would change. The most interesting result probably concerns the intelligibility of sounds when using the carpet interface, showing that participants had difficulties in gauging the level of energy parameters (high, low, medium) without hearing a sonic reference close in time. This aspect could be solved if, as pointed out by some of the participants, the carpet was part of a daily routine and users had time to get used to the sonifications and their different states. This could only be tested via a longitudinal study, after re-designing the prototype based on the results of this test. Overall participants showed interest in the idea of accessing home energy information through a sonic interface. The carpet interface received positive feedback by the participants, who overall found it engaging and imagined multiple possible use cases for it.

8. CONCLUSIONS

This paper investigates a sonic interaction design method to promote energy efficient behaviour. As mentioned in the literature review, very few experiments of real-time sonification of home energy data have been explored in previous research projects, and the overall field of household sonic interfaces is a fairly new research area. Specifically, our experiment had the objective of exploring easily understandable and non-intrusive representation of data in the home environment, through sonic interaction design. After building the prototype of an energy-aware sonic carpet, we developed a testing procedure to evaluate intelligibility of sounds and user experience. Our next design iteration will build on the results of this test to develop new sonifications and interactions.

This experiment allowed to identify aspects to be further explored in future work as well as ideas that should instead be excluded. For example, guided by the positive reaction of participants to the idea of having an interactive sonic object in their home, future work will include both further developing the carpet design, and experimenting with different sonic interactions, objects and energy metaphors.

We aim to deploy a more advanced design in a number of households for a longitudinal study. This will allows us to further investigate of the link between of auditory memory and learnability. As this kind of data does not change quickly, it is likely that users would need to rely on the memory of a repeated experience in everyday life for a period of time to fully become acquainted with this type of sonic interaction. Such a longitudinal study in households will also involve continuous measurements of energy consumption, allowing to quantitatively evaluate the effectiveness of the implemented device in terms consumption reduction. Moreover, the listening tests showed that participants had very diverse capabilities to interpret sounds, as well as personal preferences related to pleasantness of sounds. This calls for a different approach to design, which should be less standardized and instead provide users with more customisation options.

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